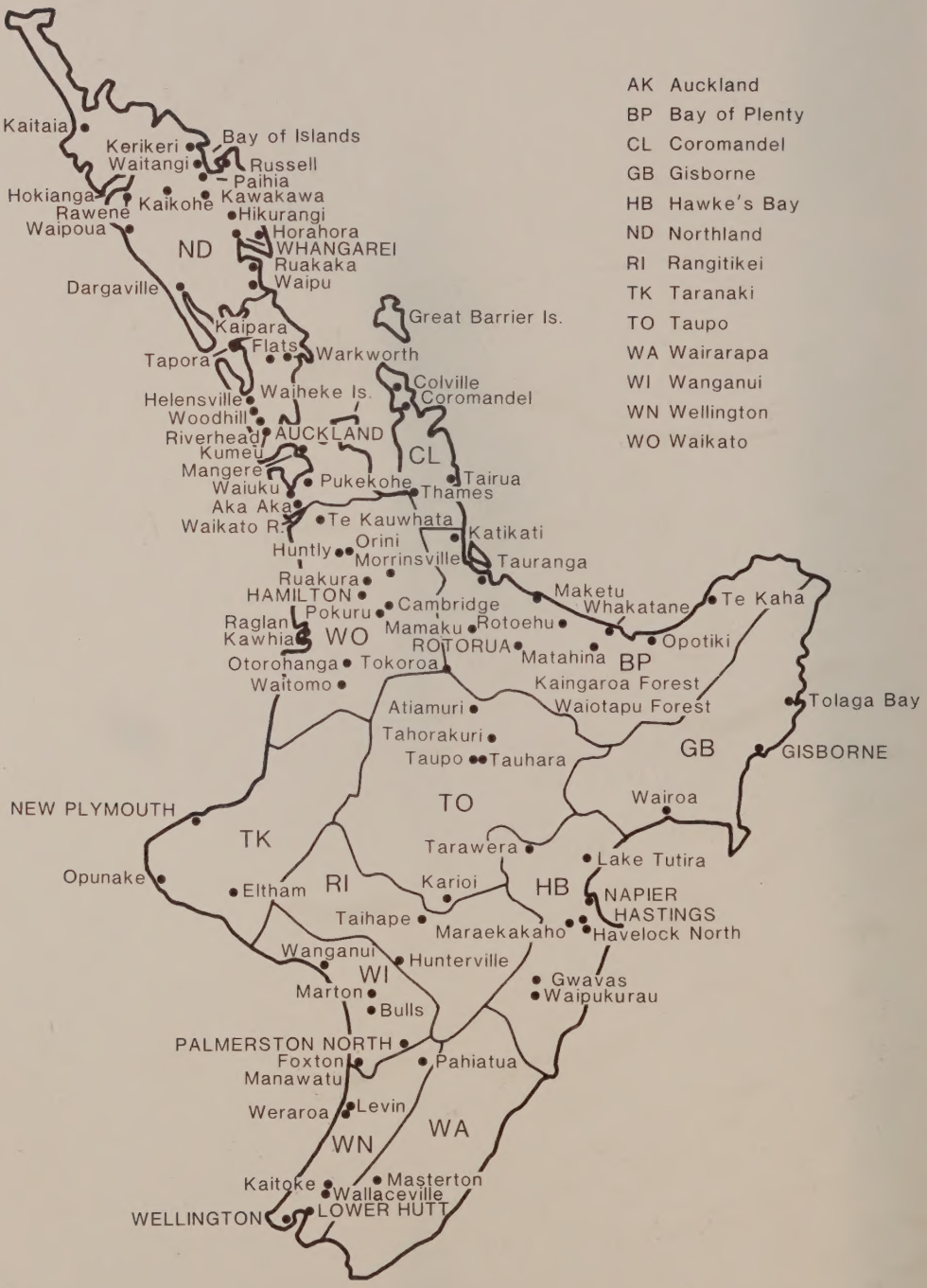
Technical Communication No. 10

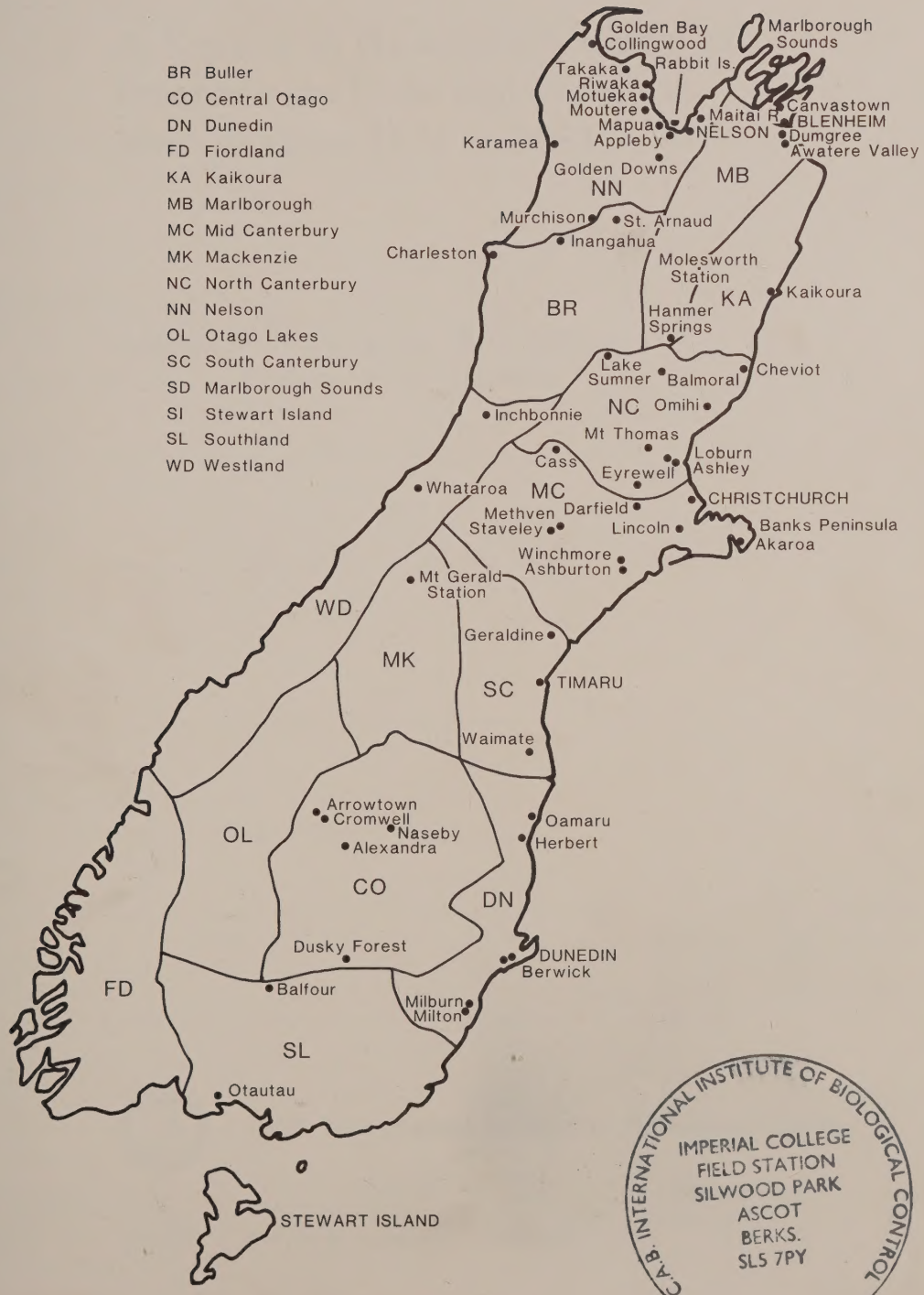
A Review of Biological Control of Invertebrate Pests and Weeds in New Zealand 1874 to 1987

Editors: P.J. Cameron, R.L. Hill,
J. Bain, W.P. Thomas

CAB International

DSIR Entomology Division


AK Auckland
BP Bay of Plenty
CL Coromandel
GB Gisborne
HB Hawke's Bay
ND Northland
RI Rangitikei
TK Taranaki
TO Taupo
WA Wairarapa
WI Wanganui
WN Wellington
WO Waikato
Kaitaia
Kerikeri
Bay of Islands
Waitangi
Russell
Paihia
Hokianga
Kaikohe
Kawakawa
Rawene
Hikurangi
Waipoua
Horahora
ND
WHANGAREI
Ruakaka
Waipu
Dargaville
Great Barrier Is.
Kaipara
Flats
Tapora
Warkworth
Colville
Coromandel
Helensville
Waiheke Is.
Woodhill
Riverhead
AUCKLAND
Kumeu
CL
Mangere
Pukekohe
Tairua
Waiuku
Thames
Aka Aka
Waikato R.
Te Kauwhata
Katikati
Huntly
Orini
Morrinsville
Tauranga
Ruakura
HAMILTON
Maketu
Whakatane
Te Kaha
Cambridge
Pokuru
Raglan
Kawhia
WO
Mamaku
Rotoehu
Opotiki
ROTORUA
Matahina
BP
Otorohanga
Tokoroa
Waitomo
Kaingaroa Forest
Waiotapu Forest
Tolaga Bay
Atiamuri
Tahorakuri
GB
GISBORNE
Taupo
Tauhara
TO
Wairoa
NEW PLYMOUTH
TK
Tarawera
Lake Tutira
Opunake
Eltham
RI
Karioi
HB
NAPIER
HASTINGS
Taihape
Maraekakaho
Havelock North
Wanganui
Hunterville
WI
Gwavas
Marton
Waipukurau
Bulls
PALMERSTON NORTH
Foxton
Pahiatua
Manawatu
Weraroa
Levin
WA
WN
Kaitoke
Masterton
Wallaceville
WELLINGTON
LOWER HUTT



C.A.B. INTERNATIONAL INSTITUTE OF BIOLOGICAL CONTROL
IMPERIAL COLLEGE
FIELD STATION
SILWOOD PARK
ASCOT
BERKS.
SL5 7PY
UK

Technical Communication No. 10

A Review of Biological Control of Invertebrate Pests and Weeds in New Zealand 1874 to 1987

Editors: P.J. Cameron, R.L. Hill,
J. Bain, W.P. Thomas

CAB International Institute of Biological Control

DSIR Entomology Division

Technical Communication No. 10
CAB International Institute of Biological Control (CIBC)

Published on behalf of DSIR Entomology Division by
CAB International
Wallingford
Oxon OX10 8DE
UK

Tel: Wallingford (0491) 32111
Telex: 8477964 (COMAGG G)
Telecom Gold/Dialcom: 84: CAU 001
Fax: (0491) 33508

Department of Scientific and
Industrial Research (DSIR)
Entomology Division
120 Mt Albert Road
Auckland 3
New Zealand

Tel: (09) 893 660
Telex: MARC NZ21623
Fax: (09) 863-330

British Library Cataloguing in Publication Data

A Review of biological control of invertebrate pests and weeds in New Zealand 1874 to 1987.
1. New Zealand. Crops. Pests. Biological Control, 1874–1987
I. Cameron, P.J. II. CAB International III. Series 632'.96'09931

ISBN 0 85198 645 5

ISSN 0956–134X

© C·A·B International and DSIR, 1989. All rights reserved. No part of this publication may be reproduced in any form or by any means, electronically, mechanically, by photocopying, recording or otherwise, without the prior permission of the copyright owners.

Printed in the UK

TABLE OF CONTENTS

	Page
LIST OF CONTRIBUTORS	vi
FOREWORD	vii
PREFACE	viii
GENERAL INTRODUCTION	ix
PART 1. Pasture Pests	1
1. *Acyrthosiphon kondoi* Shinji, bluegreen lucerne aphid and *A. pisum* (Harris), pea aphid	3
2. *Costelytra zealandica* (White), grass grub	9
3. *Heteronychus arator* (F.), black beetle	17
4. *Listronotus bonariensis* (Kuschel), Argentine stem weevil	23
5. *Sitona discoideus* Gyllenhal, sitona weevil	27
6. *Sminthurus viridis* (L.), lucerne flea	29
7. *Therioaphis trifolii* (Monell) f. *maculata* (Buckton), spotted alfalfa aphid	33
8. *Wiseana* spp., porina	39
PART 2. Field Crop and Vegetable Pests	43
9. Agromyzidae, leaf miners	45
10. *Agrotis ipsilon* (Hufnagel), greasy cutworm	51
11. Aphididae, aphids	55
12. *Chrysodeixis eriosoma* (Doubleday), green looper	67
13. *Coleophora frischella* L., whitetipped clover casebearer and *C. spissicornis* (Haworth), banded clover casebearer	73
14. *Helicoverpa armigera* (Hübner), tomato fruitworm	87
15. *Helix aspersa* Müller, brown garden snail	93
16. *Listroderes difficilis* Germain, vegetable weevil	97
17. *Mayetiola destructor* (Say), hessian fly	101
18. *Metopolophium dirhodum* (Walker), rose-grain aphid	105
19. *Mythimna separata* (Walker), cosmopolitan armyworm	107
20. *Nezara viridula* (L.), green vegetable bug	111
21. Noctuidae, noctuid moths	115
22. *Phthorimaea operculella* (Zeller), potato tuber moth	119
23. *Pieris rapae* (L.), small white butterfly	129
24. *Plutella xylostella* (L.), diamondback moth	135
25. *Spodoptera litura* (F.), tropical armyworm	143

PART 3. Fruit Crop Pests 145

26. *Caliroa cerasi* (L.), cherryslug 147
27. *Coccus hesperidum* L., brown soft scale 153
28. *Cydia molesta* (Busck), oriental fruit moth 155
29. *Cydia pomonella* (L.), codling moth 161
30. *Dasineura pyri* (Bouché), pear leafcurling midge and *D. mali* Kieffer, apple leafcurling midge 171
31. Diaspididae, armoured scales 177
32. *Edwardsiana crataegi* (Douglas), Froggatt's apple leaf hopper 183
33. *Epiphyas postvittana* (Walker), lightbrown apple moth 187
34. *Eriosoma lanigerum* (Hausmann), woolly apple aphid 197
35. *Forficula auricularia* L., European earwig 201
36. *Icerya purchasi* Maskell, cottony cushion scale 207
37. *Oemona hirta* (F.), lemon tree borer 213
38. *Panonychus ulmi* (Koch), European red mite 217
39. Pseudococcidae, mealybugs 223
40. *Saissetia oleae* (Olivier), black scale 237
41. *Scolypopa australis* (Walker), passionvine hopper 241
42. *Tetranychus urticae* Koch, two-spotted spider mite 245
43. *Trialeurodes vaporariorum* (Westwood), greenhouse whitefly 251

PART 4. Forestry Pests 255

44. *Asterodiaspis* spp., pit scales 257
45. *Eriococcus coriaceus* Maskell, gum tree scale 263
46. *Gonipterus scutellatus* (Gyllenhal), gum tree weevil 267
47. *Hylastes ater* (Paykull), black pine bark beetle and *Hylurgus ligniperda* (F.), golden haired bark beetle 271
48. *Megastigmus spermotrophus* Wachtl, Douglas fir seed chalcid 277
49. *Paropsis charybdis* Stål, eucalyptus tortoise beetle 281
50. *Phyllonorycter messaniella* (Zeller), oak leaf-miner 289
51. *Pineus laevis* (Maskell), pine twig chermes 295
52. *Sirex noctilio* F., sirex wood wasp 299
53. *Tuberculatus annulatus* (Hartig), oak aphid 307

PART 5. Weeds 309

54. *Acaena anserinifolia* (Forster & G. Forster) J. Armstrong, piripiri 313
55. *Ageratina adenophora* (Sprengel) R. King & H. Robinson, Mexican devil weed 317
56. Algal blooms, algal blooms 321
57. *Alternanthera philoxeroides* (C. Martius) Grisebach, alligator weed 325
58. Aquatic macrophytes, waterweeds 331
59. *Carduus nutans* L., nodding thistle 339

60. *Cirsium arvense* (L.) Scopoli, Californian thistle 343
61. *Cytisus scoparius* (L.) Link, broom 347
62. *Digitalis purpurea* L., foxglove 351
63. *Hypericum perforatum* L., St John's wort 353
64. *Rubus fruticosus* L. agg., blackberry 357
65. *Senecio jacobaea* L., ragwort 361
66. *Ulex europaeus* L., gorse 367

PART 6. Nuisance Pests 373

67. *Austrosimulium* spp., black flies 375
68. Calliphoridae, blow flies 381
69. Muscidae, muscid flies 387
70. *Vespula germanica* (F.), German wasp and *V. vulgaris* (L.), common wasp 395

INDEX 401

LIST OF CONTRIBUTORS

ALLAN, D.J., Entomology Division, DSIR, Private Bag, Auckland.
BAIN, J., Forest Research Institute, Private Bag, Rotorua.
BERRY, J.A., Entomology Division, DSIR, Private Bag, Auckland.
BISHOP, D.M., MAFTech, Wallaceville Animal Research Centre, Private Bag, Upper Hutt.
CAMERON, P.J., Entomology Division, DSIR, Private Bag, Auckland.
CHARLES, J.G., Entomology Division, DSIR, Private Bag, Auckland.
CLEARWATER, J.R., Entomology Division, DSIR, Private Bag, Auckland.
CROSBY, T.K., Entomology Division, DSIR, Private Bag, Auckland.
DENTENER, P.R., Entomology Division, DSIR, Private Bag, Auckland.
DONOVAN, B.J., Entomology Division, DSIR, Private Bag, Christchurch.
DYMOCK, J.J., Entomology Division, DSIR, Private Bag, Auckland.
EDWARDS, J., Biological Science Department, Waikato University, Private Bag, Hamilton.
FARRELL, J.A., Entomology Division, DSIR, Private Bag, Christchurch.
FAULDS, W., Forest Research Institute, Private Bag, Rotorua.
FERGUSON, A.M., Entomology Division, DSIR, Private Bag, Christchurch.
GOURLAY, A.H., Entomology Division, DSIR, Private Bag, Christchurch.
HAYES, A.J., Entomology Division, DSIR, Private Bag, Auckland.
HEATH, A.C.G., MAFTech, Wallaceville Animal Research Centre, Private Bag, Upper Hutt.
HILL, M.G., Entomology Division, DSIR, Private Bag, Auckland.
HILL, R.L., Entomology Division, DSIR, Private Bag, Christchurch.
JESSEP, C.T., Entomology Division, DSIR, Private Bag, Christchurch.
KAY, M.K., Forest Research Institute, Private Bag, Rotorua.
MACFARLANE, R.P., Entomology Division, DSIR, Private Bag, Christchurch.
MARKWICK, N.P., Entomology Division, DSIR, Private Bag, Auckland.
MARTIN, N.A., Entomology Division, DSIR, Private Bag, Auckland.
MCGREGOR, P.G., Entomology Division, DSIR, Private Bag, Palmerston North.
MORALES, C.F., Entomology Division, DSIR, Private Bag, Auckland.
NUTTALL, M.J., Forest Research Institute, Private Bag, Rotorua.
PEARSON, W.D., Entomology Division, DSIR, Private Bag, Christchurch.
ROBERTS, L.I.N., Ministry for the Environment, Private Bag, Wellington.
ROWE, D.K., MAFFish, Fisheries Research Centre, P.O. Box 297, Wellington.
RUSSELL, D., Overseas Development Natural Resources Institute, Chatham Maritime, ME4 4TB, United Kingdom.
STEVEN, D., Entomology Division, DSIR, Private Bag, Auckland.
STUFKENS, M.W., Entomology Division, DSIR, Private Bag, Christchurch.
SUTHERLAND, O.R.W., Entomology Division, DSIR, Private Bag, Auckland.
SYRETT, P., Entomology Division, DSIR, Private Bag, Christchurch.
THOMAS, W.P., Entomology Division, DSIR, Private Bag, Christchurch.
WALKER, G.P., Entomology Division, DSIR, Private Bag, Auckland.
WALKER, J.T.S., Entomology Division, DSIR Research Orchard, Private Bag, Hastings.
WEARING, C.H., Entomology Division, DSIR, Private Bag, Auckland.
WIGLEY, P.J., Entomology Division, DSIR, Private Bag, Auckland.
VALENTINE, E.W., R.D.1, Upper Moutere, Nelson.
ZONDAG, R., Forest Research Institute, Private Bag, Rotorua.

FOREWORD

This book continues a series of regional reviews of biological control which started in 1960 with the publication of a volume on Australia and Papua New Guinea, the first of a series of Technical Communications. Subsequent volumes have covered Canada, the Ethiopian [Afrotropical] Region, South-East Asia and the Pacific Region, Western and Southern Europe and the Commonwealth Caribbean and Bermuda.

The series had its origin in a resolution of the 1950 Commonwealth Agricultural Bureaux Quinqennial Review Conference which recommended a survey of the results of biological control in member countries. As time has passed the series has evolved. Information on export of biotic agents has also been published. Some volumes have included all countries in a region, when the authors had access to previously unpublished or otherwise relatively inaccessible information. Some, including two volumes updating progress in Canada, have included other techniques of biological control as well as the introduction of exotic biotic agents (classical biological control).

However, documentation of introductions has been the principal objective of the series. As well as providing valuable information for biological control practitioners, accurate and authoritative information on introductions has also provided data for improving our understanding of colonisation by exotic species. This has improved biological control practice, and helped to publicise biological control and establish it as a central component in pest management.

Therefore it is a pleasure to welcome the present volume on the results of biological control in New Zealand which was one of the pioneers of classical biological control. The results described in this book provide a number of instructive examples, many of which have been little known hitherto. The authors, editors, and all those who have assisted in preparing the book for publication are to be congratulated for the very considerable effort they have put into publicising the achievements of biological control in New Zealand.

D.J. Greathead
Director
CAB International Institute of Biological Control

PREFACE

In the Sixth meeting of the New Zealand Institute in Wellington in 1891, Sir James Hector introduced Mr Albert Koebele, a Californian entomologist who had on a previous visit to New Zealand collected several thousand Vedalia ladybirds which were preying on *Icerya purchasi*. The ladybirds were released in California and *Icerya* was quickly brought under control. Mr Koebele's second visit to New Zealand was to repay this benefit by introducing and liberating in Auckland other insect parasitoids from America which he hoped would largely prey on the other 'blights' existing here.

The free exchange of insect parasitoids and predators now has a long and successful history that has been well documented in this CIBC series of reviews. It is now fitting that New Zealand completes coverage of Commonwealth countries in this comprehensive and timely review. It comes at a time when there is increasing pressure world-wide for diminished pesticide use, and there is an increasing place and opportunity for biological control, as a component of integrated pest management.

The exchange of biological control agents is conducted against the background of a developing spectrum of controls, at both scientific and political levels. Entomologists place strong emphasis on a knowledge of the biology and systematics of both the biological control agent and the target pest or weed so as to facilitate choice of the most suitable agent and to optimise the prospects of successful rearing, release and establishment. These are sensible and essential measures, but in such complex ecological systems there can be no guarantee that there will be successful establishment or control. Biological control agents are comprehensively checked under quarantine conditions, as to their specificity, before releases are made. Many countries now have well developed consultative processes to consider the potential impacts, costs and benefits of the biological control agent; so that all who may be affected by control of the target pest or weed may have their views considered. These concerns for efficacy, specificity and safety and for the public good are now being considered in legislation in some countries. A balanced assessment of the needs of agricultural development and environmental concerns is essential and a growing feature of the discipline of biological control.

A feature that may not always have received proper attention or support in the past years however, is thorough evaluation of the impact of each biological control attempt upon the target. In the context of future development of biological control, and increasing public interest in its operation, its effectiveness and its justification, it is essential that each attempt be properly documented and evaluated. Whilst each case may be unique, aspects of success or failure may provide directions for future attempts, and the identification of benefit and demonstration of safety will be of substantial value.

This review therefore is an attempt to document New Zealand's record and achievements in biological control, and it will provide an essential basis for future planning. Throughout the chapters, the close involvement of Entomology Division of New Zealand's Department of Scientific and Industrial Research, the Forest Research Institute and the CAB International Institute of Biological Control is quite clear. We appreciate the close co-operation and excellent working relationship.

J.F. Longworth
Director
Entomology Division
DSIR

GENERAL INTRODUCTION

This is the first comprehensive review of the importation, release, evaluation and management of organisms imported for the biological control of invertebrate pests and weeds in New Zealand. It follows the preparation of a list of invertebrates imported for biological control (Cameron *et al.* 1987) but updates and documents these records, particularly where the information is previously unpublished. The book is divided into six sections with the chapters in each section arranged alphabetically by pest genus or group. It does not cover all biological control programmes in similar detail, but emphasises those areas for which the records have not previously been compiled or are dispersed through the literature, in unpublished reports, or in the files of the respective organisations. Where the information has been published, the chapters often provide only brief summaries with literature sources. Most of the authors are members of organisations which are currently involved in introductions for biological control. Entomology Division of the Department of Scientific and Industrial Research (DSIR) imports invertebrates for biological control of agricultural and horticultural pests through quarantine facilities at Auckland and Lincoln. Agents for control of forest insect pests are imported through the Forest Research Institute (FRI) facilities at Rotorua. Fish have been imported for aquatic weed control by a branch of the Ministry of Agriculture and Fisheries (Now MAFFish). Evaluation of introduced organisms is carried out by these and other organisations.

Several previous reviews, annotated lists and unpublished reports have contributed substantially to this book. These include Miller *et al.* (1936), which reviews all biological control of weeds and insect pests to that date and the review of biological control of weeds from 1927-48 by Miller (1970). Gourlay (1930) and Valentine (1967) provide valuable host records for entomophagous insects, including records of establishment for introduced species. The preparation of an annotated catalogue of New Zealand Hymenoptera (Valentine & Walker 1989) has ensured the consistency of nomenclature and records for this most important group of biological control agents. This review was also greatly assisted by the unpublished compilations and indexes of B.B. Given and E.W. Valentine (DSIR files). Although unpublished file records have been used extensively in the review, they were not necessarily searched if the published information was consistent. The most important of these records have been extracted and deposited in FRI file E 86 at Rotorua, or in DSIR file BC 1/4 located at the Mt Albert Research Centre, Auckland.

The geographic isolation and temperate maritime climate of New Zealand have restricted the number of pests able to reach and colonise New Zealand as well as limiting the diversity of natural enemies, as documented in this review. The climate lacks the extremes associated with the continental areas of the world, in particular, summers are cooler and winters are less intense. Over the 2,000 km length of New Zealand, from approximately 34°S to 47°S (Fig. 1), the climate varies from subtropical to cool temperate (Table 1). Although the pest complement is limited, so is the area from which potential control agents can be obtained. Overseas searches for natural enemies have been concentrated on similar temperate areas in Europe, Australia, South America and southern Africa.

The dominant land-use is pastoral farming on rye grass/white clover improved pastures which form 13.4% of the New Zealand vegetation cover (Blaschke *et al.* 1981). By comparison, cropping and horticulture total 6.3% and exotic forests 1.8% of vegetation cover. Export earnings from pastoral farming and the associated forage crops exceed NZ$4,500 million annually, field crops and vegetables account for about NZ$500 million, fruit NZ$700 million, and production forestry NZ$750 million (Anonymous 1987, Halsted 1988). Because of the importance of pastoral farming, a significant effort has been directed against pasture pests, particularly the endemic grass grub, *Costelytra zealandica* (White). This has resulted in unique programmes using exotic natural enemies to control endemic pests. However, the

Table 1 Climate records for a range of New Zealand locations

	Kaitaia 35°S		Hamilton 38°S		Christchurch 44°S		Dunedin 46°S	
	Jan.	Jul.	Jan.	Jul.	Jan.	Jul.	Jan.	Jul.
TEMPERATURE °C								
Mean daily max.	25.2	16.2	23.9	13.5	21.5	10.3	20.4	10.0
Mean daily min.	14.2	7.2	11.6	3.1	11.6	1.4	9.0	–0.4
RAINFALL (mm)								
Monthly	75	134	83	125	55	71	70	45

majority of biological control programmes have been directed against self-introduced insects and weeds which are pests of introduced crops, using natural enemies located overseas and imported through quarantine facilities for release in New Zealand.

The recent increase in the area of land used for horticultural crops is a major feature of agricultural development. This has led to the increased importance of horticultural pests and the development of integrated pest management which in turn has encouraged the use

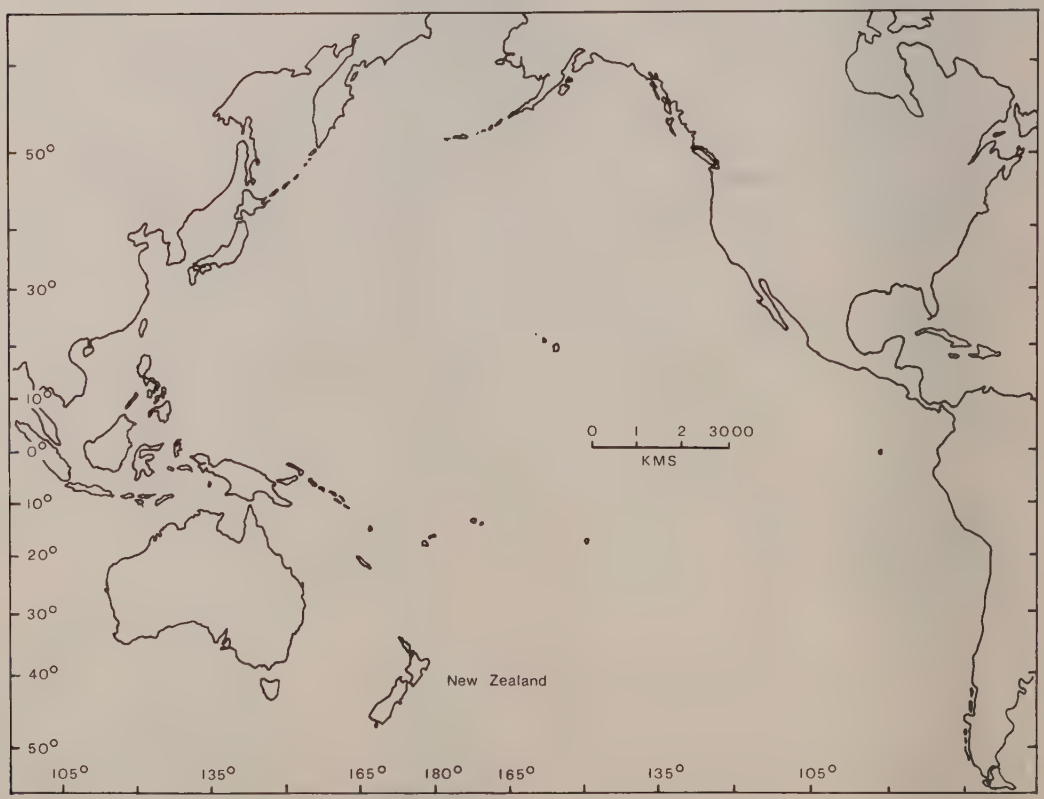


Figure 1 New Zealand in the Pacific

of natural enemies. This has not necessarily been by the introduction of further parasitoids and predators, but has emphasised the use of natural enemies and the minimum use of insecticides. Concerns about insecticide resistance, chemical residues, and growing interest in organic production are also leading to increased research on natural enemies and on biological control. For economic and environmental reasons, insecticide and herbicide use is declining, further highlighting the need for research into alternative control methods.

Production forestry is based on nearly 1.1 million hectares of forest plantations comprising mainly conifers, dominated by a single species, *Pinus radiata* D. Don. Biological control in forestry has been concentrated on the major insect pest of radiata pine, *Sirex noctilio* F., and more recently on insect pests of *Eucalyptus* spp., particularly *Paropsis charybdis* Stål which is a major constraint to the use of several desirable species of *Eucalyptus*.

The pattern of biological control introductions reflects the importance of particular insect pest and weed problems unique to New Zealand, but has also been influenced by world developments in the availability of agents for use against cosmopolitan pests. For example, the largest number of importations (36) have been directed against the endemic pest *C. zealandica*, while 21 introductions were made against the cosmopolitan potato tuber moth, *Phthorimaea operculella* (Zeller), as part of a world-wide programme. Records show that, since about 1925, strong links have developed between the Department of Agriculture, DSIR or FRI and the CAB International Institute of Biological Control (CIBC) or its predecessors. A large number of importations have originated from Europe (98), but Australia has been the major source (106 records) for natural enemies of Australian pests, cosmopolitan pests and New Zealand endemic pest species. North American contacts are also demonstrated by the 62 importation records from that area.

Table 2 Summary of the number of agents imported and released, their current status, and the number of targets on which an impact has been reported.

Target Group	Number of Targets	Agents					Number of targets for which impact has been reported
		Species introduced	Records	Released	Recovered (not established)	Established	
Pasture	8	52	55	41	9	6	2
Field crops & vegetables	17	103	117	79	6	16	8
Fruit	18	70	77	49	5	21	6
Forest	10	43	48	22	0	13	6
Weeds	13	40	41	23	3	11	2
Nuisance insects	4	13	13	11	1	3	0
TOTAL	70	321	351	225	24	70	24

A summary of the importation, release and establishment records is given in Table 2. The term 'record' in this table refers to an importation of an agent considered to be a separate entity. Thus, continual importation of one species from one source over a defined period is regarded as one record. Importation of a species from different sources, or re-importation after a significant time interval, is considered to represent the introduction of a new agent and is regarded as a new record. Table 2 also summarises the cases where an impact on the population level or the pest status of a target has been reported. Details of this impact are provided in the chapter on each target pest and summarised in the introductions to each Part of the review.

The history of entomological organisations and their staff is detailed by Ramsay & Singh (1982). Until 1936, biological control research was carried out either by the Cawthron Institute or by the Department of Agriculture. In 1937, responsibility for all biological control research was transferred to the joint DSIR/Cawthron Institute Entomology Research Station in Nelson. In 1956 the Station became Entomology Division of DSIR. Biological control work began at the Forest Research Institute in 1950.

A historical synopsis of biological control practice is provided by Miller (1964) who commented on the introduction of *Coccinella undecimpunctata* L. in 1874, the first deliberate introduction of a biological control agent into New Zealand (Chapter 11). Miller (1964) also commented on the export of *Rodolia cardinalis* (Mulsant) from New Zealand to California in 1889, which led to control of the cottony cushion scale, *Icerya purchasi* Maskell, a landmark in the early history of biological control (Chapter 46). Early projects such as these were carried out by individuals such as the orchardist and naturalist R.A. Wight and T.W. Kirk (later of the Department of Agriculture) co-operating with colleagues overseas. Wight and Kirk also published much of the information about the importation and export of biological control agents into New Zealand prior to 1910.

Biological control expanded in the 1920s and included historically important introductions against blow flies (Calliphoridae, Chapter 68) by D. Miller (then at the Department of Agriculture), and woolly apple aphid (*Eriosoma lanigerum* (Hausmann), Chapter 34) by R.J. Tillyard (Cawthron Institute). E.S. Gourlay summarised this period in his unpublished 'History of the Entomology Department, Cawthron Institute' (DSIR files). During the period 1929 to 1936 A.F. Clark was involved in forestry projects at the Cawthron Institute. Notable projects in the 1930s included work on the brassica pests small white butterfly, *Pieris rapae* (L.) and diamondback moth, *Plutella xylostella* (L.), which is documented by J. Muggeridge (Department of Agriculture) and B.B. Given (DSIR) (see Chapters 23 & 24). A renewal of interest in biological control of the grass grub *Costelytra zealandica* dominated the records from 1949 to 1954 when B.B. Given shipped thynnine wasps from Australia (Chapter 2).

There was a significant increase in importations in several project areas in the 1960s. This followed the formation of a biological control group in Entomology Division which included E. Collyer, W. Cottier, R.A. Cumber, B.B. Given, C.T. Jessep, D. Miller, W.P. Thomas, J.S. Timlin and E.W. Valentine. The most extensive programmes during this period included the importation of aphid predators, and parasitoids for *Coleophora* spp., *Phthorimaea operculella* (Zeller) and *Epiphyas postvittana* (Walker). The search for natural enemies of *C. zealandica* was transferred to South America and generated shipments of parasitoids and predators into the early 1970s. Importation of parasitoids for *Sirex noctilio* F. also increased during the 1960s under the supervision of G.B. Rawlings and then R. Zondag at the Forest Research Institute. Recent directions in biological control have been dominated by the arrival of lucerne pests in New Zealand, the extension of integrated pest management in horticulture, a concentration of effort on *Eucalyptus* pests, and the re-emphasis of biological control of weeds.

The plans for this review were finalised in 1986 and the first chapters were submitted in August 1987 which, unless otherwise stated, is the completion date for records. Authors have indicated where more recent information has been included.

Many people assisted in the preparation of this review. We particularly acknowledge R.L. Harding, H.A. Martin and S.M. Tucker for typing many of the manuscripts, T.K. Crosby and G.W. Ramsay for general discussions, G.P. Walker and D.W. Helmore for preparation of maps, M.L. Lessiter for photographic prints, and R.L. Kannemeyer, J. Boyle and A.H. Gourlay for general assistance. The scientific names were checked by J.M. Fry and D.J.Girling (CAB International Institute of Biological Control) and members of the staff of CAB International Institute of Entomology, particularly A.K. Walker, and of the British Museum (Natural History). Plant names have been altered to conform with Webb *et al.* (1988). The common names for insects and mites conform to Ferro *et al.* (1977). We would like to thank

E.W. Valentine who was involved in the early preparation of this review. We especially acknowledge the assistance of A.H. Greathead who checked the draft manuscripts, proof-read the review and compiled the index.

P.J. Cameron
R.L. Hill
J. Bain
W.P. Thomas Editors

Literature Cited

Anonymous (1987) Agriculture and forest industries. Pp. 408-456 in New Zealand official year book 1987-88, vol. 92.

Blaschke, P.M.; Hunter, G.G.; Eyles, G.O.; Van Berkel, P.R. (1981) Analysis of New Zealand's vegetation cover using land resource inventory data. *New Zealand journal of ecology* 4, 1-19.

Cameron, P.J.; Hill, R.L.; Valentine. E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242, 51 pp.

DSIR, Entomology Division, file BC 1/4

Ferro, D.N.; Lowe, A.D.; Ordish, R.G.; Somerfield, K.G.; Watt, J.C. (1977) Standard names for common insects of New Zealand. *Bulletin of the Entomological Society of New Zealand* 4, 42 pp.

Gourlay, E.S. (1930) Preliminary host-list of the entomphagous insects in New Zealand. *New Zealand Department of Scientific and Industrial Research bulletin* 22, 13 pp.

Halsted, J.V. (1988) Export statistics. Fresh fruit leads horticultural exports. *The orchardist of New Zealand* 61, 34-37.

Miller, D. (1964) Historical synopsis of biological control practice in New Zealand. *New Zealand science review* 22, 4-6.

Miller, D. (1970) Biological control of weeds in New Zealand 1927-1948. *New Zealand Department of Scientific and Industrial Research information series* 74, 104 pp.

Miller, D.; Clark, A.F.; Dumbleton, L.J. (1936) Biological control of noxious insects and weeds in New Zealand. *New Zealand journal of science and technology* 18, 579-593.

Ramsay, G.W.; Singh, P. (1982) Guide to New Zealand entomology. *Bulletin of the Entomological Society of New Zealand* 7, 72 pp.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Valentine, E.W.; Walker, A.K. (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, (in press)

Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. (1988) Flora of New Zealand. 4. Naturalised pteridophytes, gymnosperms, dicotyledons. Botany Division, DSIR, Christchurch, New Zealand. 1365 pp.

PART 1.

Pasture Pests

Grasslands sown with improved grasses and clover now form 35% of New Zealand's land area and production from these pastures is responsible for about 65% of New Zealand export earnings (Kerr 1984). The development of these improved grasslands has favoured some native insect pests, especially grass grub, *Costelytra zealandica* (White), and porina, *Wiseana* spp. Dumbleton (1942) described severe damage by grass grub as early as 1911. In a recent evaluation of the status of pasture pests, East & Pottinger (1984) classified *C. zealandica* and *Wiseana* spp. as persistent pests of widespread national importance. Attempts to control these species have continued over the years, and have included biological control which was commenced in 1921. Organochlorine insecticides were widely used for 20 years until the 1960s (Hoy 1969) when insecticide residues and insecticide resistance prompted renewed interest in biological control. Because the major pests were endemic, successful introductions required the use of natural enemies which were sufficiently polyphagous to attack new hosts. For this reason large numbers of species were tested in New Zealand and overseas. A total of 35 species has been imported for grass grub. Agents were selected with reference to their ecological range as well as their host range, and these factors led to major overseas searches in Australia by B.B. Given, and in South America by D.C. Lloyd of CIBC. The difficulties in establishing exotic parasitoids on native species have so far proved too great and none of the introduced species have persisted (Chapters 2 & 8). Recent biological control research on *C. zealandica* and *Wiseana* spp. has emphasised inundative release of pathogens rather than inoculative release of parasitoids or predators, and the development of management practices to conserve natural enemies.

Pests of overseas origin also attack pasture grasses in New Zealand and have been targets for biological control. Of these pests, *Listronotus bonariensis* (Kuschel) is considered nationally important whereas *Heteronychus arator* (F.) is locally damaging (East & Pottinger 1984). Parasitoids have been introduced from areas where *L. bonariensis* is indigenous in South America (Chapter 4), and natural enemies of *Heteronychus arator* (F.) were studied in southern Africa by E.W. Valentine and shipped to New Zealand (Chapter 3). Neither of these programmes has been successful to date.

The most recent importations against pasture pests have included general ground dwelling predators, and are amongst the few attempts world wide to use such natural enemies. These importations were directed against *C. zealandica*, *Wiseana* spp., *Graphognathus leucoloma* (Boheman) and *H. arator*. Although the natural predatory fauna of New Zealand pastures is considered to be depauperate, this condition may have been exacerbated over the years of organochlorine usage. Recent studies suggest that predator populations may be increasing as insecticide use has declined (Robertson *et al.* 1981).

Lucerne, *Medicago sativa*, is also used as pasture for rotational grazing and production of hay. The land area in lucerne has almost halved from a peak of 220,000 ha in the mid 1970s. This decline is partly attributed to increases in the pest fauna (Kain & Trought 1982). The arrival of *Sitona discoideus* Gyllenhal, *Acyrthosiphon kondoi* Shinji, *A. pisum* (Harris) and *Therioaphis trifolii* (Monell) between 1974 and 1982 significantly affected lucerne production and the costs of pest control. Subsequent loss of confidence in lucerne contributed to a reduction in the area newly planted. Multidisciplinary research programmes were rapidly developed. The establishment of parasitoids against all these pests reflects the cooperation between New Zealand, Californian and Australian researchers, and the benefits of exchang-

ing natural enemies. Evaluation of these programmes is continuing (see Chapters 1, 5 & 7) and suggests that measurable impacts have been achieved in the control of *S. discoideus*, *A. kondoi* and *A. pisum*.

Literature Cited

Dumbleton, L.J. (1942) The grass grub: a review of the problem in New Zealand. *New Zealand journal of science and technology* A 23, 305-321.

East, R.; Pottinger, R.P. (1984) The cost of pasture pests. *New Zealand agricultural science* 18, 136-140.

Kain, W.M.; Trought, T.E.T. (1982) Insect pests of lucerne in New Zealand. Pp. 49-59 in Wynne-Williams, R.B. (ed.), Lucerne for the 80's. Agronomy Society of New Zealand, special publication 1.

Kerr, J.P. (1984) Pasture – the export earner. *New Zealand agricultural science* 18, 87-89.

Hoy, J.M. (1969) Grass grub – the problem insect. *New Zealand journal of agricultural science* 4, 18-20.

Robertson, L.N.; Davison, R.H.; Firth, A.C. (1981) Pasture management to control Australian soldier fly. *New Zealand journal of experimental agriculture* 9, 109-113.

Acyrthosiphon kondoi Shinji, bluegreen lucerne aphid and *Acyrthosiphon pisum* (Harris), pea aphid (Homoptera: Aphididae)

P.J. CAMERON and G.P. WALKER

Pest Status

Bluegreen lucerne aphid (BGA), *Acyrthosiphon kondoi* Shinji was first reported in New Zealand in 1975 (Cox & Dale 1977) five months after it arrived in Australia. It spread through most of New Zealand in less than a year. The first record of pea aphid (PA), *Acyrthosiphon pisum* (Harris) was from the Auckland area in 1976 (Archibald *et al.* 1979) and this species spread as quickly as BGA. Both species are pests of lucerne (*Medicago sativa*), especially the cultivar Wairau which was most common at that time in New Zealand. BGA also affects yields of white clover seed, and is recorded from red clover, *Lotus* spp., lentils and trefoils (Hill 1979). In addition to lucerne, PA is known to attack peas, broad beans (Archibald *et al.* 1979), and some clovers, vetches and trefoils (Hill 1979).

Both these *Acyrthosiphon* spp. are parthenogenetic in New Zealand climatic conditions, whereas PA forms sexuals and lays eggs in cold climates in the northern hemisphere. In New Zealand, adults and nymphs are therefore available to natural enemies all year round. BGA has a lower temperature threshold for development than PA (Rohitha & Penman 1983) and this results in differing seasonal activity and pest status (Gaynor *et al.* 1979). Peak populations of BGA typically occur in spring as lucerne recommences growth and, less commonly, in autumn. Chapman (1984) considered that BGA has been especially troublesome in lucerne growing areas in the southern North Island and the northern South Island. PA can become the dominant species in the summer (Cameron *et al.* 1979) and may be more common in the North Island. Populations of both aphid species have declined in the Taupo, Waikato and Auckland areas since 1979 (Cameron unpublished).

Damage to lucerne is characterised by stunting of plants and yellowing of leaves. Additionally, BGA injects a toxin into plants which causes misshapen leaves and shortened internodes. The effects on crop production are dependent on the density of aphid populations, the season, and the period for which they persist. Kain *et al.* (1979) recorded production losses in lucerne of up to 60% and 30% when BGA was dominant in spring and autumn, and up to 48% in summer when PA was more common. Kain & Trought (1982) provide management guidelines which indicate that aphid populations below 30 per stem can be tolerated on taller lucerne in spring and summer. Such unsprayed lucerne provides opportunities for natural enemy populations to increase and spread.

Background

Several general aphid predators in New Zealand now include PA and BGA in their host range. In lucerne these predators are commonly *Coccinella undecimpunctata* L. (Coccinellidae), *Micromus tasmaniae* (Walker) (Hemerobiidae), *Melanostoma fasciatum* (MacQuart) (Syrphidae) and *Nabis capsiformis* Germar (Nabidae) (Thomas 1977, Cameron *et al.* 1979). In contrast to California (Neuenschwander *et al.* 1975), there is only one common predatory species in each of these families, and in New Zealand these predators are generally not well synchronized with lucerne aphid populations. Therefore, any control they exert is usually unpredictable. The exception is *Micromus tasmaniae* which has a relatively low threshold

temperature for development (Syrett & Penman 1981) and is capable of responding to early season aphid population increases (Cameron *et al.* 1983).

Prior to introductions for biological control, *Aphelinus abdominalis* (Dalman) (Aphelinidae) was the only parasitoid of PA and BGA, and although it was uncommon it was present in all main lucerne growing areas (Cameron *et al.* 1979).

The presence of fungal pathogens of BGA has been described by Hall *et al.* (1979), while Cameron & Milner (1981) showed that PA suffered greater rates of infection than BGA. The recorded pathogens in New Zealand are *Erynia neoaphidis* Remaudière & Hennebert, *Conidiobolus obscurus* (Hall & Dunn) Remaudière & Keller, *Entomophthora planchoniana* Cornu and *Zoophthora phalloides* Batko. *Erynia kondoiensis*, which Milner *et al.* (1983) described from Australia, is not present. Although PA in particular can suffer significant mortality from *E. neoaphidis*, extensive epizootics of any fungal pathogens are reliant on suitably moist conditions. These pathogens may therefore provide little control over the summer. No fungal pathogens have been introduced.

Control measures are now based on the use of resistant cultivars, together with grazing or harvesting management and the use of insecticides. Although the use of insecticides is the least compatible with natural enemies, pirimicarb has been noted as less toxic than other compounds to *M. tasmaniae* (Syrett & Penman 1980) and *N. capsiformis* (Cameron *et al.* 1983) and is recommended for conservation of beneficial insects. Resistant cultivars have played a major role in limiting the impact of PA, BGA and spotted alfalfa aphid (SAA) in North America. These cultivars have been imported and New Zealand cultivars have also been developed and released (Dunbier & Easton 1982). Some cultivars demonstrate aphid tolerance and support moderate populations which provide hosts for beneficial insects.

In New Zealand, the approach to biological control of PA and BGA was based on North American experience in which parasitoids were first introduced against PA in 1958 (Clausen 1978) and against BGA in the late 1970s (Gonzales *et al.* 1978). The most common naturally occurring parasitoids in North America include *Aphidius pisivorus* C.F. Smith and *Praon pequodorum* Viereck (Aphidiidae). These have been augmented by *Aphidius smithi* Sharma & Subba Rao and *A. ervi* Haliday, which have in turn become the most common parasitoids of PA (Mackauer & Kambhampati 1986). In Europe *A. ervi* is the dominant parasitoid of PA, followed at much lower levels by *A. urticae* Haliday, *Praon barbatum* Mackauer and *A. picipes* (Nees) (Stary 1972, Cameron *et al.* 1984). Introductions into New Zealand were based largely on material supplied by D. Gonzales (Gonzales *et al.* 1978) with emphasis on *A. ervi*, which is a parasitoid of both PA and BGA. The introduction of general aphid predators which may also attack PA and BGA is considered separately in Chapter 11.

Importations, Releases and Recoveries

The initial introduction of parasitoids from cultures at the University of California at Riverside in 1977 and 1978 is described in Cameron *et al.* (1979). The species introduced as *Aphidius 'urticae'* was subsequently described by Stary *et al.* (1980) as *A. eadyi*. The five species sent were identified as strains according to the locations from which they were collected (Table 1.1). The continued importation of *A. ervi* from 1979 to 1981 is recorded in Cameron & Walker (in press), who also give detailed release and recovery records for *A. ervi*, *A. eadyi* and *A. smithi*.

Aphidius eadyi Stary, Gonzales & Hall (Hymenoptera: Aphidiidae)

The release of 1580 *A. eadyi* at Helensville near Auckland in 1977 resulted in the establishment of this species (Cameron *et al.* 1979, 1981). It dispersed at a rate of approximately 120 km per year, and spread naturally to the Hamilton area by early 1979. *A. eadyi* was later redistributed to the Rotorua, Taupo and Manawatu areas of the North Island, and to Lincoln in the South Island (Cameron & Walker in press). By 1987 it was established in all lucerne

Table 1.1 Importations and releases of Aphidiidae (Hymenoptera)

Species	Source	Strains	Dates Imported	Release Period	No. released Individual strains	No. released Combined strains
Aphidius eadyi	Riverside	Morocco	30 May 77	1977-79	1,580	
Aphidius ervi	Riverside	Japan	18 Mar. 77	1977-78	1,840	
		Israel	18 Mar. 77	1977-78		
		Greece	18 Mar. 77	1977-78	250	
		Tashkent (USSR)	15 Dec. 77	1977-79	9,100	
		Belgium	9 Apr. 77	1977-81	19,400	10,840
	Tasmania	Tasmania	2 Oct. 79 -16 Dec. 80	1979-81	15,500	
	Rothamsted	UK	13 Nov. 81 & 16 Dec. 81	1981	1,600	
Aphidius smithi	Riverside	Afghanistan	15 Dec. 77	1977-80	290	34,917
		California	15 Dec. 77	1977-80	105	
		Israel	15 Dec. 77	1977-78	1,910	
		Iran	15 Dec. 77	1977-78	135	
Ephedrus plagiator	Riverside	Japan	18 Mar. 77	1977-78	4,530	
Praon barbatum	Riverside	Chumsan (USSR)	15 Dec. 77	1977-78	30	
		Iran	15 Dec. 77	1977-78	12	

growing areas of New Zealand. Parasitism of PA reached 30-40%, and following the establishment of *A. eadyi* there was a decline in PA populations which may in part have been associated with this parasitoid (Cameron *et al.* 1981).

Aphidius ervi Haliday (Hymenoptera: Aphidiidae)

This species was obtained from three sources and was imported over a period of almost four years. Three strains obtained from Riverside (Table 1.1) were reared individually and released at sites detailed in Cameron *et al.* (1979). Two further strains were released in very small numbers and cultures were not maintained. Occasional recoveries were made, but only the Tashkent strain persisted, and this only in the South Island (Cameron & Walker in press). The establishment of this strain is considered to have produced the current distribution of *A. ervi* in the central and southern lucerne growing areas of the South Island (Cameron & Walker in press).

Further importations of *A. ervi* were made in 1979 and 1980 from Tasmania. This strain included material which originated from Japan, as well as a naturalised Tasmanian strain. It was reared separately as well as in combination with the Belgian strain. Releases were confined to the North Island, and were followed by recoveries at Wairakei near Taupo. From 1979 to 1982 *A. ervi* became increasingly common in the Taupo area and in 1982 was predominant over *A. eadyi* (Cameron & Walker in press). By 1986, it appeared that *A. ervi* had spread throughout the North Island from this establishment.

Aphidius smithi Sharma & Subba Rao (Hymenoptera: Aphidiidae)

Four strains of *A. smithi* were received from Riverside, but only three were cultured, and two of these as a mixed strain (Table 1.1). All major releases were made in the Auckland area (Cameron *et al.* 1979, Cameron & Walker in press) and the only confirmed recoveries were from field cages. This species is difficult to distinguish from *A. eadyi* (Stary *et al.* 1980),

but P. Stary (pers. comm.) indicated there were no other recoveries amongst specimens he examined from New Zealand. *A. smithi* is at present considered not to be established in New Zealand (Cameron & Walker in press).

Ephedrus plagiator (Nees) (Hymenoptera: Aphidiidae)

All the releases and recoveries of this species are described in Cameron *et al.* (1979). Some early recoveries were made in Hawke's Bay and Lincoln but these did not persist and releases were not continued beyond 1978.

Praon barbatum Mackauer (Hymenoptera: Aphidiidae)

Cameron *et al.* (1979) noted the release of 30 individuals of a U.S.S.R. strain of this species. A further strain imported from Iran (via Riverside) was cultured at Lincoln and also released in small numbers (DSIR files). No field recoveries are recorded.

Evaluation

The rapid spread of *A. eadyi* through New Zealand is an indication of its success as a species. Its success in controlling PA is more difficult to assess. Although parasitised PA are common, accurate measures of parasitism show that *A. eadyi* rarely kills more than 30-40 % of a population. Comparisons of areas with and without this parasitoid, and comparisons before and after its establishment (Cameron *et al.* 1981), showed that PA exceeded damage thresholds less frequently when *A. eadyi* was present. Although the appearance of *A. eadyi* was the dominant change occurring in this two year period, other factors may have contributed to the decline of PA.

A. ervi has been slower to establish and spread, but has become predominant over *A. eadyi*. Rearing of parasitoids from mixed PA and BGA populations has shown that *A. ervi* prefers BGA and has also partly displaced *A. eadyi* from PA (Cameron & Walker in press). Overall rates of parasitism have therefore not increased with the establishment of *A. ervi*, but BGA is now parasitised as well as PA. Although this would be expected to have an effect on aphid species composition, no clear change has been detected. Hyperparasitoids, particularly *Dendrocerus carpenteri* (Curtis) (Megaspilidae), have been reared from an average of 47% of *Aphidius* mummies (Walker & Cameron 1981) and may reduce the impact of parasitoids.

The evaluation of biological control agents for aphids has often been confined to observations on single agents, making it difficult to provide valid quantitative comparisons between mortality factors. Fungal pathogens can cause high mortality, but this is reliant on high humidity and therefore the effects are dependent on weather. Most predators are also unpredictable in their occurrence and unreliable in the control they exert on lucerne aphids.

Of the few common predators, *M. tasmaniae* is best synchronised with lucerne aphids (Cameron *et al.* 1983) and is the predator most likely to provide control. In Australia, *M. tasmaniae* has been considered to control spotted alfalfa aphid in spring (Allen 1984), and the ability of this predator to respond in cool temperatures appears largely responsible for its relative success. Parasitism shows a more even seasonal distribution than fungal disease, for example, *A. eadyi* demonstrates the best synchrony of a natural enemy with PA (Cameron *et al.* 1983), which is its only host.

Since 1979-80 we have noted that PA and BGA populations have declined steadily at a number of northern North Island sites. This decline is likely to have resulted from a number of factors including the establishment of parasitoids. For example, the replacement of some susceptible cultivars with aphid resistant lucerne, together with better management practices, may have reduced aphid populations in some areas. Whatever the cause of population declines, natural enemies including parasitoids are now more abundant by comparison with lucerne aphids, and are therefore more likely to provide control.

Conclusions

The establishment of *A. eadyi* and *A. ervi* has contributed to the control exerted by natural enemies on PA and BGA. The eventual dominance of *A. ervi* may result from its polyphagous nature which allows this parasitoid to utilize both *Acyrthosiphon* spp. in lucerne, as well as alternative hosts in adjacent crops. This species now appears to be making a more stable contribution than *Aphidius eadyi* to aphid control in lucerne. This delayed dominance of *A. ervi*, particularly in the North Island, has also been observed in North America (Mackauer & Kambhampati 1986) and may suggest that although *A. eadyi* is more efficient at high host densities, *A. ervi* can persist better at lower densities.

In Australia *A. ervi* is the only introduced parasitoid established against *Acyrthosiphon* spp. (Milne 1986). It has been shown capable of achieving high rates of parasitism in the field and exerting control in experimental conditions. In Europe and North America *A. ervi* is the dominant species, augmented by one or two other specific or polyphagous parasitoids. The parasitoid fauna in New Zealand now appears as well balanced as that overseas. These parasitoids, together with other natural enemies, resistant cultivars and management techniques have reduced reliance on insecticides, and no further introductions are recommended.

Literature Cited

Allen, P.G. (1984) The impact of predators on spotted alfalfa aphid in lucerne pasture during spring in South Australia. Pp. 375-380 in Hodek, I. (ed.), Ecology of Aphidophaga 2. Academia, Praha.

Archibald, R.D.; Cox, J.M.; Deitz, L.L. (1979) New records of plant pests in New Zealand. III. Six species of Homoptera. *New Zealand journal of agricultural research* 22, 201-207.

Cameron, P.J.; Allan, D.J.; Walker, G.P.; Wightman, J.A. (1983) Management experiments on aphids (*Acyrthosiphon* spp.) and beneficial insects in lucerne. *New Zealand journal of experimental agriculture* 11, 343-349.

Cameron, P.J.; Milner, R.J. (1981) Incidence of *Entomophthora* spp. in sympatric populations of *Acyrthosiphon kondoi* and *A. pisum*. *New Zealand journal of zoology* 8, 441-446.

Cameron, P.J.; Powell, W.; Loxdale, H.D. (1984) Reservoirs for *Aphidius ervi* Haliday (Hymenoptera: Aphidiidae), a polyphagous parasitoid of cereal aphids (Hemiptera: Aphidiidae). *Bulletin of entomological research* 74, 647-656.

Cameron, P.J.; Thomas, W.P.; Hill, R.L. (1979) Introduction of lucerne aphid parasites and a preliminary evaluation of the natural enemies of *Acyrthosiphon* spp. (Hemiptera: Aphididae) in New Zealand. Pp. 219-223 in Crosby, T.K.; Pottinger, R.P. (eds) *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Cameron, P.J.; Walker, G.P. (in press) Release and establishment of *Aphidius* spp. (Hymenoptera: Aphidiidae), parasitoids of pea aphid and bluegreen aphid in New Zealand. *New Zealand journal of agricultural research*.

Cameron, P.J.; Walker, G.P.; Allan, D.J. (1981) Establishment and dispersal of the introduced parasite *Aphidius eadyi* (Hymenoptera: Aphidiidae) in the North Island of New Zealand, and its initial effect on pea aphid. *New Zealand journal of zoology* 8, 105-112.

Chapman, R.B. (1984) Pasture pests. Pp. 119-142 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Clausen, C.P. (ed.) (1978) Introduced parasites and predators of arthropod pests and weeds: a world review. *United States Department of Agriculture, Agriculture Research Service, Agriculture Handbook* 480, 545 pp.

Cox, J.; Dale, P.S. (1977) New records of plant pests in New Zealand. II *New Zealand journal of agricultural research* 20, 109-111. DSIR, Entomology Division, file BC 1/4

Dunbier, M.W.; Easton, H.S. (1982) Longer stand life with new cultivars. Pp. 121-126 in Wynn-Williams, R.B. (ed.), Lucerne for the 80's. Agronomy Society of New Zealand, special publication 1.

Gaynor, D.L.; Kain, W.M.; Atkinson, D.S.; Aliver, M.J. (1979) Observations on *Acyrthosiphon kondoi* and *A. pisum* on lucerne crops in the southern North Island, New Zealand (Hemiptera: Aphididae). Pp. 134-138 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Gonzales, D.; White, W.; Hall, J.; Dickson, R.C. (1978) Geographic distribution of Aphidiidae (Hym.) imported to California for biological control of *Acyrthosiphon kondoi* and *Acyrthosiphon pisum* (Hom.: Aphididae). *Entomophaga* 23, 239-248.

Hall, I.M.; Lowe, A.D.; Given, B.B.; Oliver, E.H.A. (1979) Fungi attacking the blue-green aphid in New Zealand. *New Zealand journal of zoology* 6, 473-474.

Hill, R.L. (1979) Bluegreen lucerne aphid, *Acyrthosiphon kondoi* Shinji, and pea aphid, *A. pisum* (Harris), life cycles. *DSIR information series* 105/28.

Kain, W.M.; Atkinson, D.S.; Oliver, M.J.; Stiefel, W. (1979) Pest assessment studies of blue green lucerne and pea aphids in the southern North Island region of New Zealand. *Proceedings of the 32nd New Zealand Weed and Pest Control Conference*, 171-179.

Kain, W.M.; Trought, T.E.T. (1982) Insect pests of lucerne in New Zealand. Pp. 49-59 in Wynn-Williams, R.B. (ed.), Lucerne for the 80's. Agronomy Society of New Zealand, special publication 1.

Mackauer, M.; Kambhampati, S. (1986) Structural changes in the parasite guild attacking the pea aphid in North America. Pp. 347-356 in Hodek, I. (ed.), Ecology of Aphidophaga. Academia, Prague and Dr W. Junk, Dordrecht.

Milne, W.M. (1986) The release and establishment of *Aphidius ervi* Haliday (Hymenoptera: Ichneumonoidea) in lucerne aphids in eastern Australia. *Journal of the Australian Entomological Society* 25, 123-130.

Milner, R.J.; Mahon, R.J.; Brown, W.V. (1983) A taxonomic study of the *Erynia neoaphidis* Remaudière & Hennebert (Zygomycetes: Entomophthoraceae) group of insect pathogenic fungi, together with a description of the new species *Erynia kondoiensis*. *Australian journal of botany* 31, 173-188.

Neuenschwander, P.; Hagen, K.S.; Smith, R.F. (1975) Predation on aphids in California's alfalfa fields. *Hilgardia* 43, 53-78.

Rohitha, B.H.; Penman, D.R. (1983) Effect of temperature on the biology of bluegreen lucerne aphid, *Acyrthosiphon kondoi*. *New Zealand journal of zoology* 10, 299-308.

Stary, P. (1972) Relative abundance of parasite species as an area-dependent phenomenon and its possible significance in biological control (Hym., Aphidiidae). *Bolletino del Laboratorio di Entomologia Agraria 'Filippo Silvestri' Portici* 30, 19-27.

Stary, P.; Gonzales, D.; Hall, J.C. (1980) *Aphidius eadyi* n.sp. (Hymenoptera: Aphidiidae), a widely distributed parasitoid of the pea aphid, *Acyrthosiphon pisum* (Harris) in the palearctic. *Entomologica scandinavica* 11, 473-480.

Syrett, P.; Penman, D.R. (1980) Comparative toxicity of insecticides to lucerne aphids and their predators. *Proceedings of the 33rd New Zealand Weed and Pest Control Conference*, 52-53.

Syrett, P.; Penman, D.R. (1981) Development threshold temperatures for the brown lacewing, *Micromus tasmaniae* (Neuroptera: Hemerobiidae). *New Zealand journal of zoology* 8, 281-283.

Thomas, W.P. (1977) Biological control of the blue-green lucerne aphid. The Canterbury situation. *Proceedings of the 30th New Zealand Weed and Pest Control Conference*, 182-187.

Walker, G.P.; Cameron, P.J. (1981) The biology of *Dendrocerus carpenteri* (Hymenoptera: Ceraphronidae), a parasite of *Aphidius* species, and field observations of *Dendrocerus* species as hyperparasites of *Acyrthosiphon* species. *New Zealand journal of zoology* 8, 531-538.

Costelytra zealandica (White), grass grub (Coleoptera: Scarabaeidae)

P.J. CAMERON and P.J. WIGLEY

Pest Status

Costelytra zealandica (White) is a native species found in indigenous tussock grasslands, and is a persistent, widespread and most important pest of improved pasture. Dumbleton (1942) described the early European development of grasslands which favoured grass grub and led to outbreaks reported as early as 1911 to 1939. Hoy (1969) noted 20 years of control with DDT until the 1960s when insecticide residues and insecticide resistance prompted renewed interest in alternative insecticides and biological control.

The larvae of grass grub feed on the roots of a wide range of plants, particularly in pasture, although they do not develop well on legumes. Fodder crops, cereals and horticultural crops such as raspberries and strawberries also are damaged by root feeding. Adults feed on the foliage of brassicas, trees and a variety of horticultural crops. Biological control programmes have generally been directed against larvae in pasture. *C. zealandica* usually lays eggs in clusters 10 to 15 cm below the soil surface. Larvae develop through three instars which feed on roots near the surface or deeper, and then overwinter at depths of 25 cm. Pupation occurs in October or November, although in cool areas with less food slow larval development leads to a two year life cycle. All these soil dwelling stages are subject to attack by pathogens and general predators, but effective parasitoids require a specialised burrowing capability.

C. zealandica is most damaging in light to medium free draining soils in Canterbury, Hawke's Bay, Taranaki and the central North Island. East & Pottinger (1984) rank grass grub nationally in their highest pasture pest category, but note that economic importance is related to grazing shortages which can vary between seasons and locations. Larval damage is most obvious from March to July. Herbage production is reduced in moderate infestations, but dense populations of up to 400/m^2 prevent regeneration of permanent pasture, and weed invasion occurs. The importance of this pest is also partly indicated by the extensive biological control efforts which have been directed against it in every decade from 1921 to 1981.

Background

Native natural enemies

Parasitoids

Given (1945) reared three native tachinid species from Melolonthinae larvae but observed that none of them attacked *C. zealandica*. Later, Thomas (1963) showed that one of these species, *Procissio cana* Hutton, parasitised 2.6% of *C. zealandica* in weedy pasture adjacent to scrub. Both Given (loc. cit.) and Thomas (loc. cit.) noted that no parasitism occurred in open grazed pasture areas. This distribution was further noted by Merton (1982) who recorded 20% parasitism of third instar larvae by *P. cana* in unimproved high country grassland, and reported the absence of the parasitoid in *C. zealandica* from lowland pasture. The presence of a nematode, *Mermis* sp. was noted by Kelsey (1951). Kelsey & Hoy (1950) considered that native parasitoid species were unlikely to prevent damaging population increases of *C. zealandica*.

Predators

Miller (1921) recorded the larvae of two species of native asilid Diptera (*Itamus varius* Walker and *Saropogon antipodus* Schiner) as predators of *Odontria* sp. larvae. Kelsey (1951)

also noted the association of asilid larvae, as well as therevids and carabids, with *C. zealandica* larvae and considered that considerable local control could be exerted. Farrell (1972) considered that adult *Thyreocephalus chloropterus* (Erichson) (Staphylinidae) and *Conoderus exsul* (Sharp) (Elateridae) larvae were facultative predators on *C. zealandica* larvae and suggested that neither species caused significant mortality. East & Pottinger (1975) considered that predation by starlings (*Sturnus vulgaris* L.), in combination with irrigation and grazing management, provided effective biological control in localised areas. These authors also noted predation by other birds and by mammals. Although the soil dwelling predatory fauna in New Zealand pasture may have local impact on smaller larvae, there are no common large predators capable of attacking large grass grub larvae (Cameron & Butcher 1979).

Pathogens

A wide range of naturally occurring pathogens have been recorded from *C. zealandica*. Fowler (1972) recorded two *Bacillus* spp., while Grimmont *et al.* (1988) identified a bacterial gut disease as *Serratia entomophila* Grimmont, Jackson, Ageron & Noonan. A small RNA virus, Flock House virus, has caused low levels of infection (Wigley & Miln 1982). Iridescent virus and rickettsial infections have also been reported (Moore *et al.* 1974). Other pathogens include fungi (Helson 1965), gregarines (Allison 1969), a *Mattesia* sp. (Miln 1978) and three microsporidian species; *Nosema takapauensis* Hall, Oliver & Given (1976), *Nosema costelytrae* Hall, Oliver & Given (1977) and *Vavraia oncoperae* (Milner & Beaton) Malone, Wigley & Dhana (1987).

The incidence of these diseases has been related to the population dynamics of grass grub by Miln (1982) who considered that disease caused delayed density dependent mortality, partly as a result of inoculum build up in dense populations. East & Wigley (1985) recorded higher levels (41%) of combined pathogen infection in declining compared with increasing populations. Jackson (1984) demonstrated that whenever high levels (greater than 30%) of amber disease, *S. entomophila*, were recorded in any one year the population levels of grass grub declined in the following season. The combined results of these three studies, conducted at diverse localities, identify disease as the predominant biotic mortality factors in grass grub population dynamics.

Overseas programmes

The potential for utilizing foreign agents for biological control of *C. zealandica* was reviewed by Dumbleton (1942). These programmes require that the exotic biological control agent should adapt to a new native host in New Zealand. The early introductions up to 1935 were mainly concerned with small scale importations and laboratory testing. Attention was then directed to the North American programme for biological control of Japanese beetle *Popillia japonica* Newman (Scarabaeidae), particularly the use of bacterial diseases and nematodes. *Bacillus popilliae* Dutky was experimentally transmitted to *C. zealandica* (Dumbleton 1945) and a trial batch of spore dust from the USDA Japanese Beetle Laboratory was used in field trials in 1948 by Kelsey (1966). Milky disease of New Zealand origin was cultured by Dutky and reimported for trials in New Zealand (Hoy 1955). None of these trials led to significant control, although full implementation of the work was limited by the wide effectiveness of DDT. Parasitoids of *P. japonica* in the U.S.A. were known not to accept Melolonthinae as hosts and were therefore not considered for importation.

An overseas search was carried out by Entomology Division from 1945 to 1952 in Australia where the varied scarab fauna is the primary centre for parasitic wasps in the subfamily Thynninae. Given (1953) investigated this fauna and identified thynnine parasitoids of *Heteronyx* spp., *Liparetrus* spp. and *Aphodius* spp. (Scarabaeidae). He collected adult thynnines feeding on nectar from the genera *Leptospermum*, *Acacia*, and *Hakea*, or on honey dew from scales or aphids. Extensive shipments were carried out from 1947 to 1952 and concentrated on those species shown to oviposit on *C. zealandica* in the laboratory in New Zealand.

From 1945 to 1947, Lloyd (1952) investigated the parasitic Thynninae in the San Carlos de Bariloche and El Bolson areas of south west Argentina. This area was considered to be an important centre for thynnine wasps, but was also chosen because of its similarity to the Canterbury high country. Lloyd (1964) established that several thynnine species parasitised Melolonthinae in Argentina, but in recommending a trial shipment of *Pseudelaphroptera brevipilosa* Duran, Lloyd considered that the thynnines' strong preference for feeding at Apiaceae (= Umbelliferae) may limit their dispersal into open New Zealand pasture. Following a tour of New Zealand in 1965, Lloyd endorsed the need for an evaluation of exotic predators (Lloyd 1965). He also noted that Apiaceae such as fennel *Foeniculum vulgare* Miller, and common aphids, may supply food sources for thynnines in some farmed areas. Shipments of Thynninae, Tachinidae and Carabidae extended from 1965 to 1973.

The European *Costelytra* project based at Delémont in 1965 and 1966 investigated European parasitoids including Tachinidae and the Tiphiidae *Scolia* sp. and *Tiphia* sp. (Mesnil 1965, 1966). No parasitism was obtained with imported *C. zealandica* and the results were considered inconclusive. Five disease microorganisms were also tested and a *Nosema* sp. reported from 20-70% of larvae. Importations of *Microphthalma europaea* Egger (Tachinidae) were carried out later, in 1967, but these were primarily directed against *Heteronychus arator* (F.).

Importations, Releases and Recoveries

The first recorded importations for control of *C. zealandica* were the neuropteran predator *Ithone fusca* Newman (Ithonidae) from Australia, and the parasitic Hymenoptera *Tiphia* sp. and *Elis* sp. (Tiphiidae: Thynninae) from the U.S.A. *I. fusca* was imported in one shipment of 6,000 eggs which were liberated in soil, but no larvae were recovered (DSIR files). No recoveries were made from importations of 46 *Elis* sp. and 178 *Tiphia* sp. cocoons (DSIR files). These unsuccessful attempts at establishment occurred from 1921 to 1922 (Miller 1936).

From 1926 to 1928 the tachinid *Microphthalma michiganensis* (Townsend) was imported from Canada (Miller 1928, 1936). The material was shipped as 2,860 infested June beetle larvae (*Phyllophaga* sp.). A total of 106 adult tachinids emerged and liberations of these were made near Wellington and in Canterbury (Miller 1928). Although no recoveries were recorded, this work indicated the feasibility of transporting material from the northern hemisphere autumn and obtaining emergence after a four week voyage to New Zealand.

From 1932 to 1936 a variety of species were imported for laboratory study. The parasitic tachinid *Isocheta* (= *Hyperecteina*) *aldrichi* (Mesnil) (= *Centeter cinerea* Aldrich) was imported from Japan in 1934 as one shipment of 396 puparia (DSIR files, Miller 1936). The thynnine *Elaphroptera dimidiata* (Haliday), imported from Chile in 1932 and 1935, did not survive consignment (DSIR files, Dumbleton 1942). In addition, six consignments comprising five species of thynnines were received from Australia in 1934-35 (DSIR files). None of these were successfully reared or released.

Hoy (1955) reported the importation of the nematode *Steinernema glaseri* Steiner, and noted that it attacked all pest species of Melolonthinae and could survive in soil plots for four and a half years. Jackson & Trought (1982) imported *S. glaseri* and *Heterorhabditis bacteriophora* Poinar from Australia and recovered both species from trials in which infected grass grub populations were shown to decline.

The search for parasitoids in Australia (Given 1953) was carried out for six years from 1945. The main collection area was south west Victoria where Melolonthinae were parasitised by a wide range of Thynninae. Given initially consigned Scoliinae, Anthoboscinae and Tachininae, but only Thynninae arrived in good condition and these formed 97 of the 100 shipments. Thirteen species comprising over 14,000 mated females were shipped. The species names listed in Table 2.1 have been derived from the names and number codes used by Given (1953), together with specimen labels from the New Zealand Arthropod Collection

Table 2.1 Thynninae imported from Australia and released in New Zealand. Code numbers and data from Given (1953); some names derived from DSIR files and specimens in NZAC.

Species	Code No.	Imported Year	Imported No.	Released No.
Ariphron tryphonoides (Smith)	22	1948-49	51	0
Eirone rufopicta (Smith)	73	1945	6	0
Lophocheilus anilitatis (Smith)	46	1948-51	798	639
Neozeleboria cryptoides (Smith)	25	1947-51	748	584
N. volatilis (Smith)	75	1949-51	737	518
Phymatothynnus sp.	24	1947-51	4489	3842
Rhagigaster unicolor lyelli Turner	K1	1952	938	149
R. comparatus Smith	28	1948-49	114	103
Tachynomyia rubella (Smith)	19	1947-51	10	6
T. paradelpha Turner	69	1948	54	23
Thynnoides rufithorax Turner	11	1947-51	2131	1416
T. senilis (Erichson)	89	1950	11	9
T. lugubris Given	66	1949-51	3994	3441

(NZAC), DSIR files, the catalogue compiled by Given (1954a) and the systematic publications (Given 1958). The species imported as '*Thynnoides gracilis*(?)', code number 11 in Given (1953), and named as *T. laeviceps* (Smith) in the NZAC is referred to as *T. rufithorax* Turner in DSIR files. The name *T. rufithorax*, as used by Cameron *et al.* (1987), is used for the three species in this review (Table 2.1). Liberations of 10,730 females were made at nine areas spread over New Zealand (Given 1953). These included over 500 individuals for each of the six main species, and over 3,000 for two of these. *T. rufithorax* was recovered from *Odontria smithi* Broun or *O. striata* White at Ashburton as shown by records of two cocoons in 1949 and two more in 1950 (DSIR files, Given 1953). Four cocoons of *Lophocheilus anilitatis* (Smith) were recorded from a field cage at Foxton in 1951 (DSIR files). No other recoveries have been reported despite extensive sampling and rearing of *C. zealandica*.

The major species imported from the CIBC Argentinian programme was the thynnine *Pseudelaphroptera brevipilosa*. Lloyd (1964) reared this thynnine from field collected larvae of both melolonthine scarabs and the weevil *Graphognathus leucoloma* (Boheman). The numbers of females or pairs consigned from 1965 to 1973 are listed in Table 2.2. Mated females were released at nine sites in the northern South Island and five sites in the northern

Table 2.2 *Pseudelaphroptera brevipilosa* shipped from Argentina and released in New Zealand; as number of females or pairs. Sources: DSIR files, Lloyd & Blackman (1966), Lloyd *et al.* (1967, 1970), Lloyd & Ahmad (1971, 1972)

Year	Number shipped	Number released	and area
1965	520	205	Marlborough
1966	15,550	12,130	Taupo, Marlborough, Nelson
1967	20,489	9,339	Nelson
1968	5,550	1,682	Nelson
1969	0		
1970	4,685	717	Nelson
1971	12,500	7,621	Waikato, Bay of Plenty, Nelson
1972	13,929	4,876	Auckland, Bay of Plenty, Nelson
1973	3,000	165	Auckland, Bay of Plenty
Total	76,178	36,735	

North Island, in the areas indicated in Table 2.2 (DSIR files). In New Zealand, 45 *P. brevipilosa* males emerged from grass grub caged in the field, and thynnine cocoons were also obtained from *G. leucoloma* larvae (DSIR files). As a result the releases from 1970 were partly directed against *G. leucoloma*. No *P. brevipilosa* were reared from field collected larvae of either host, but male thynnines were recalled by attracting them to tethered females 13 days after release in the Marlborough area. No further recoveries were reported.

Three carabid species were imported as adults and released in 1968-70 (Table 2.3). Larvae of all species were obtained in laboratory rearing. Surveys for over a year, including pitfall traps in the main release areas, did not recover any released carabids (DSIR files). Eleven parasitic tachinids were imported over a similar period (Table 2.3), but none of these developed successfully on *C. zealandica* or *Odontria* spp. *Morphodexia barrosi* (Brèthes) was reared on the dynastine, *Pericoptus truncatus* (F.). Relatively few tachinids were released and none were recovered.

Table 2.3 Carabidae and Tachinidae shipped from Argentina and released in New Zealand. Sources: DSIR files, Lloyd & Rechencq (1969), Lloyd *et al.* (1970).

Species	Shipped No.	Released No.	Area
CARABIDAE (1968-70)			
Barypus clivinoides (Curtis)	805	631	Nelson, Marlborough
Cnemalobus gayi Putzeys	309	153	Marlborough
Pterostichus (*Trirammatus*) *unistriatus* (Dejean)	821	587	Nelson
TACHINIDAE (1968-69)			
Anodontura sp.	210	0	
Dasyuromyia sp.			
D. inornata (Walker)			
D. tarsalis Aldrich	364	94	Nelson
D. sternalis Aldrich			
D. sarcophagidea (Bigot)			
Morphodexia nigra Aldrich	312	60	Nelson
M. clausa Aldrich	10	0	
M. barrosi (Brèthes)	22	0	
Psecacera chilensis Bigot	4	0	
Trichoprosopus latifrons Aldrich	104	0	

Evaluation

The introductions of *Ithone fusca*, *Elis* sp., *Tiphia* sp. and *Microphthalma michiganensis* prior to 1930 can be considered as speculative because of the low numbers imported and the failure to gain development of the parasitoids on *C. zealandica*. Later introductions of Tachinidae and Carabidae were not recovered and had no impact on *C. zealandica*.

The Australian search produced the first records of exotic parasitoid development on *C. zealandica*. Given (1953) reported that six species of Thynninae oviposited in grass grub in laboratory tests and selected species for consignment on this basis. Five of these species laid only two to seven eggs, but *Thynnoides rufithorax* laid 265 eggs and 23 cocoons were formed from the hosts, *Odontria autumnalis* Given and *C. zealandica*. Given (1953) considered that the recovery of four cocoons of this parasitoid at Ashburton showed its establishment, but no further specimens were found and there was no effect on *C. zealandica*.

The successful recovery records for *P. brevipilosa* were confined to experimental field cage rearing and successful recall of males in the field. These results indicate an early failure to establish and therefore a lack of impact on *C. zealandica* populations.

Although nematodes have generally been used as microbial pesticides and do not spread significantly, they have been shown to have persistent effects on *C. zealandica*. In laboratory tests Kain *et al.* (1982) found that the indigenous species *S. glaseri* was infective at considerably lower temperatures than *H. bacteriophora*. Field applications of *S. glaseri* in December caused considerable grass grub mortality, but mid-summer and autumn applications were less successful, a result attributable to unfavourable soil moisture and temperature conditions. Recently, Jackson & Wouts (1987) found that imported *Heterorhabditis* sp. (V16) persisted in the soil to cause considerable mortality a year after application to irrigated pasture.

Recently there has been considerable interest in the development of the enteric bacterium *Serratia entomophila* for inundative application to pasture for grass grub control. In the most recent of a series of papers, Jackson *et al.* (1988) report the use of a sub-surface application technique which produced a 51% decline in larvae and pupae. *S. entomophila* is now being developed as a biological insecticide.

Conclusions

The sparse fauna of native natural enemies of Scarabaeidae in New Zealand appears not to have wide impact on pests in improved pasture, leaving vacant niches which could be filled by the introduction of exotic species. Past introduction programmes have generally emphasised the requirement to import parasitoids of Melolonthinae, as hymenopteran natural enemies tend to be specific to this subfamily. Although the Thynninae have been identified as the most promising candidates, very little success was obtained in rearing them. This difficulty is related to their specialised behaviour patterns in which the male carries the female to nectar sources and to areas containing host larvae (Given 1954b, 1957). Such complex patterns, including territoriality, are likely to be easily disturbed in attempts to relocate adults. Tachinids can also require specialised rearing methods, but as fewer of these parasitoids were imported and tested, the acceptability of *C. zealandica* is unclear. The lack of suitable umbelliferous and myrtaceous plants as nectar sources and shelter is also likely to have limited the establishment success of thynnines in most New Zealand pastures. However, the recovery of *Thynnoides rufithorax* and *Lophocheilus anilitatis*, demonstrated that *C. zealandica* could be acceptable for thynnine oviposition and development in some New Zealand conditions. Cameron *et al.* (1979) considered that under these circumstances the introduction of very large numbers may be required to take advantage of rare establishment events. Future proposals for thynnine introductions should therefore at least match the previous programmes in quality and quantity of importation and release. The work of Given (1953) and Lloyd (1952, 1964) indicates that *Thynnoides rufithorax* and *Pseudelaphroptera brevipilosa* should be included in any such proposals.

The establishment of predatory Carabidae may be less difficult than parasitoids because of their polyphagous habits. However, this is partially countered by the low reproductive rate and long generation time for carabids. Failure to establish predators in New Zealand may indicate that the specific release areas were ecologically unsuitable, and that larger releases over greater areas would have increased the chances of establishment. The use of general predators is discussed further in Chapter 3 on *Heteronychus arator*.

The introduction of pathogens and nematodes has been restricted to their application in the form of biological insecticides rather than their release for inoculative establishment. While some good results have been achieved with nematodes, storage problems, the lack of a low temperature infective strain, and low soil moisture conditions are serious limitations to their widespread use. Significant research has also been carried out to develop management practices which will conserve naturally occurring pathogens. The development of *S. entomophila* as a bacterial insecticide is a major advance in grass grub biological control. It appears likely that this bacterium has considerable potential for use in the highly productive grass grub prone regions of Canterbury, Taranaki and central North Island. However, extension of inundative applications to less profitable and steeper pastoral regions will await

the development simple application techniques. Although there is a wide range of endemic pathogens of grass grub, Wigley *et al.* (1986) considered that there may still be potential for selecting and introducing exotic pathogens for biological control. The identification of suitable pathogens with capability for natural dispersal would benefit farmers in a wide range of topographies and pasture systems.

Acknowledgements

B.B. Given and W.P. Thomas commented on drafts of this review.

Literature Cited

Allison, F.R. (1969) A study of the eugregarines of the grass grub (larvae of *Costelytra zealandica* (White), Melolonthinae), with a description of three new species. *Parasitology* 59, 663-682.

Cameron, P.J.; Butcher, C.F. (1979) Pitfall trapping and soil sampling for Scarabaeidae (Coleoptera) and possible predators in some Northland and Auckland pastures. Pp. 113-117 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Cameron, P.J.; Valentine, E.W.; Butcher, C.F. (1979) Propects for biological control of pasture Scarabaeidae (Coleoptera) in New Zealand. Pp. 213-216 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242, 51 pp.

Dumbleton, L.J. (1942) The grass grub: a review of the problem in New Zealand. *New Zealand journal of science and technology* A 23, 305-321.

Dumbleton, L.J. (1945) Bacterial and nematode parasites of soil insects. *New Zealand journal of science and technology* A 27, 76-81.

East, R.; Pottinger, R.P. (1975) Starling (*Sturnus vulgaris* L.) predation on grass grub (*Costelytra zealandica* (White), Melolonthinae) populations in Canterbury. *New Zealand journal of agricultural research* 18, 417-452.

East, R.; Pottinger. R.P. (1984) The cost of pasture pests. *New Zealand agricultural science* 18, 136-140.

East, R.; Wigley, P.J. (1985) Causes of grass grub (*Costelytra zealandica* (White)) population collapse in the northern North Island of New Zealand. Pp. 191-200 in Chapman, R.B. (ed.) *Proceedings of the 4th Australasian Conference on Grassland Invertebrate Ecology*. Caxton Press, Christchurch.

Farrell, J.A.K. (1972) Observations on soil-inhabiting insect populations of improved pasture in Nelson province, with particular reference to *Costelytra zealandica* (White) (Col., Scarabaeidae). *New Zealand journal of agricultural research* 15, 878-892.

Fowler, M. (1972) A new milky disease organism from New Zealand. *Journal of invertebrate pathology* 19, 409-410.

Given, B.B. (1945) Tachinid parasites attacking melolonthid larvae in New Zealand. *Transactions of the Royal Society of New Zealand* 75, 321-323.

Given, B.B. (1953) General report on a search for parasites of Melolonthinae in Australia. *New Zealand journal of science and technology* B 34, 322-340.

Given, B.B. (1954a) A catalogue of the Thynninae (Tiphiidae, Hymenoptera) of Australia and adjacent areas. *New Zealand DSIR bulletin* 109, 89 pp.

Given, B.B. (1954b) Evolutionary trends in the Thynninae (Hymenoptera: Tiphiidae) with special reference to feeding habits of Australian species. *Transactions of the Royal Society of London* 105, 1-10.

Given, B.B. (1957) Observations on behaviour of Australian Thynninae. *Proceedings of the 8th Pacific Science Congress* IIIA, 1265-1274.

Given, B.B. (1958) Notes on Australian Thynninae. II. The genera *Dimorphothynnus*, *Rhagigaster* and *Eirone*. III. The genus *Thynniodes*. *Proceedings of the Linnean Society of New South Wales* 83, 309-336.

Grimmont, P.A.D., Jackson, T.A.; Ageron, E.; Noonan, M.J. (1988) *Serratia entomophila* sp. nov., a species associated with amber disease in New Zealand grass grub, *Costelytra zealandica*. *International journal of systematic bacteriology* 38, 1-6.

Hall, I.M.; Oliver, E.H.A.; Given, B.B. (1976) *Nosema takapauensis* n. sp. a microsporidian parasite of larvae of *Costelytra zealandica* (Coleoptera: Scarabaeidae) in New Zealand. *New Zealand journal of zoology* 3, 257-260.

Hall, I.M.; Oliver, E.H.A.; Given, B.B. (1977) *Nosema costelytrae* n. sp. a microsporidian parasite of larvae of *Costelytra zealandica* (Coleoptera: Scarabaeidae) in New Zealand. *New Zealand journal of zoology* 4, 1-3.

Helson, G.A.H. (1965) Entomogeneous microorganisms of New Zealand. *Transactions of the Royal Society of New Zealand* 6, 1-6.

Hoy, J.M. (1955) The use of bacteria and nematodes to control insects. *New Zealand science review* 13, 56-57.

Hoy, J.M. (1969) Grass grub – the problem insect. *New Zealand agricultural science* 4, 18-20.

Jackson, T.A. (1984) Honey disease, an indicator of population decline in grass grub. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 229-233.

Jackson, T.A.; Trought. T.E.T. (1982) Progress with use of nematodes and bacteria for the control of grass grub. *Proceedings of the 35th New Zealand Weed and Pest Control Conference*, 103-106.

Jackson, T.A.; Wouts, W.M. (1987) Delayed action of an entomophagous nematode (*Heterorhabditis* sp. (V16)) for grass grub control. *Proceedings of the 40th New Zealand Weed and Pest Control Conference*, 33-35.

Jackson, T.A.; Pearson J.F.; Broad, T.M.; O'Callaghan, M.; Mahanty, H.K. (1988) Subsurface application of the bacterium *Serratia entomophila* for control of grass grub in Canterbury. *Proceedings of the 41st New Zealand Weed and Pest Control Conference*, 108-112.

Kain, W.M.; Bedding, R.A.; van der Mespel, C.J. (1982) Preliminary evaluations of parasitic nematodes for grass grub (*Costelytra zealandica* (White)) control in central Hawke's Bay of New Zealand. *New Zealand journal of experimental agriculture* 10, 447-450.

Kelsey, J.M. (1951) Grass-grub and grass caterpillar control. *New Zealand journal of agriculture* 83, 113-122.

Kelsey, J.M. (1966) Incidence of *Bacillus popilliae* (Dutky) in *Costelytra zealandica* (White) larvae. *New Zealand entomologist* 3(5), 67-68.

Kelsey, J.M.; Hoy, J.M. (1950) Grass grub control. *Proceedings of the New Zealand Grasslands Association* 12, 88-94.

Lloyd, D.C. (1952) Biological observations on some thynnids of western Patagonia. *Bulletin of entomological research* 42, 707-719.

Lloyd, D.C. (1964) Report on investigation of natural enemies of Melolonthinae in temperate South America. Season 1963-64. CIBC unpublished report, 19 pp.

Lloyd, D.C. (1965) Tour of New Zealand, February – July, 1965. CIBC unpublished report, 18 pp.

Lloyd, D.C.; Ahmad, R. (1971) Investigations on natural enemies of some pasture and alfalfa insects in Argentina. CIBC unpublished report, 20 pp.

Lloyd, D.C.; Ahmad, R. (1972) Investigations on natural enemies of some pasture and alfalfa insects in Argentina. CIBC unpublished report, 17 pp.

Lloyd, D.C.; Blackman, R.L. (1966) Investigations on natural enemies of Melolonthinae and Hepialidae. CIBC unpublished report, 20 pp.

Lloyd, D.C.; Rechencq, F. (1969) Investigations of natural enemies of Melolonthinae and Hepialidae in Argentina. CIBC unpublished report, 17 pp.

Lloyd, D.C.; Ahmad, R.; Rechenq, F. (1970) Investigations of Melolonthinae and Hepialidae in Argentina. CIBC unpublished report, 17 pp.

Lloyd, D.C.; Blackman, R.L.; Henderson, I.F. (1967) Investigations of natural enemies of Melolonthinae and Hepialidae in South America. CIBC unpublished report, 35 pp.

Malone, L.A.M.; Wigley, P.J.; Dhana, S. (1987) Identity of a Microsporidium from three New Zealand pasture insects: *Costelytra zealandica* (Coleoptera, Scarabaeidae), *Wiseana* spp. (Lepidoptera, Hepialidae), and (*Listronotus bonariensis* Coleoptera, Curculionidae). *Journal of invertebrate pathology* 49, 135-144.

Merton, J.M. (1982) Interaction of the tachinid *Procissio cana*, with its host the New Zealand grass grub, *Costelytra zealandica*. Pp. 161-168 in Lee, K.E. (ed.) *Proceedings of the 3rd Australasian Conference on Grassland Invertebrate Ecology*. South Australian Government Printer, Adelaide.

Mesnil, L.P. (1965) Report on the work done in 1965 on the *Costelytra* project for New Zealand. CIBC unpublished report, 12 pp.

Mesnil, L.P. (1966) Report on the work done in 1965 on the *Costelytra* project for New Zealand. CIBC unpublished report, 5 pp.

Miller, D. (1921) Life history of the New Zealand grass grub. *New Zealand journal of agriculture* 23, 199-203.

Miller, D. (1928) Establishment of beneficial insects. Summary of recent work under Agriculture Department. *New Zealand journal of agriculture* 35, 283-289.

Miller, D. (1936) Biological control of field crops and animal insect pests. *New Zealand journal of science and technology* 18, 592-593.

Miln, A.J. (1978) Protozoan parasites of *Costelytra zealandica* (Coleoptera: Scarabaeidae) in New Zealand. *New Zealand entomologist* 6, 392-399.

Miln, A.J. (1982) The role of disease in the population dynamics of grass grub (*Costelytra zealandica* (White)). Pp. 147-154 in Lee, K.E. (ed.) *Proceedings of the 3rd Australasian Conference on Grassland Invertebrate Ecology*. South Australian Government Printer, Adelaide.

Moore, S.G.; Kalmakoff, J.; Miles, J.A.R. (1974) An irridescent virus and rickettsia from the grass grub *Costelytra zealandica* (Coleoptera: Scarabaeidae). *New Zealand journal of zoology* 1, 205-210.

Thomas, W.P. (1963) A natural enemy of common grass grub, *Costelytra zealandica* White. *New Zealand entomologist* 3 (2), 15-18.

Wigley, P.J.; Miln, A.J. (1982) The distribution and ecology of Flock House virus in *Costelytra zealandica* (Coleoptera: Scarabaeidae). *New Zealand journal of zoology* 1, 205-210.

Wigley, P.J.; Malone, L.A.M.; Dhana, S. (1986) Screening insect pathogens for pest control. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 126-129.

Heteronychus arator (F.), black beetle (Coleoptera: Scarabaeidae)

P.J. CAMERON and W.P. THOMAS

Pest Status

Heteronychus arator (F.) originates from South Africa, but is considered to have been introduced into New Zealand from New South Wales and was first recorded from Waiheke Island in 1937 (Todd 1959). It has relatively high temperature requirements and is confined to areas with a mean annual screen temperature above 13°C (Watson 1979). It can be a major pest throughout Northland and in sandy coastal districts of Auckland, Bay of Plenty, Gisborne, Waikato and northern Taranaki. Pastures in which paspalum (*Paspalum dilatatum* Poiret) and kikuyu (*Pennisetum clandestinum* Hochstetter) are dominant are most favourable for development (King *et al.* 1981), but most pasture grasses are attacked as well as various crop plants including maize, potatoes, kumara (sweet potato) and strawberries (Chapman 1984).

Todd (1959) gives a full account of the life history and biology. Adult beetles overwinter and lay eggs from October to January. Larvae develop rapidly from January to March and cause most damage to pasture root systems during this period. The larval stages, which are most susceptible to natural enemies, are therefore available for a relatively short period compared with melolonthine scarabaeids which overwinter as larvae.

Black beetle outbreaks occur sporadically and are closely associated with above average spring temperatures (Watson 1979), which favour development and survival. Dense populations result in flight activity, dispersal and widespread damage. Population increases have been noted since the use of dieldrin in pastures was prohibited in 1967 (Esson 1973). The last serious outbreak of *H. arator* occurred in the early to mid-1970s and led to renewed interest in research on this pest, including biological control programmes.

Background

Natural enemies

There are no recorded parasitoids of *H. arator* in New Zealand. Several potential predators have been noted in black beetle infested pasture, but there are no definite field records, nor any suggestion that predators cause significant mortality. Cameron & Butcher (1979) surveyed infested pastures in Northland and Auckland and recorded the presence of four harpaline Carabidae which were shown to be capable of predation on small scarabaeid larvae. The elaterids *Conoderus* spp. were present at all sites but the larvae were considered incapable of attacking third instar black beetle larvae. In this same survey, the staphylinid, *Thyreocephalus orthodoxus* Olliff, was locally more abundant than *Conoderus* spp. and was shown to be capable of feeding on eggs, all larval stages, and pupae of black beetle (Butcher 1979). Although the larger carabids, *Metaglymma* spp. and *Mecodema* spp., have been associated with scarabaeids in New Zealand (Brown 1967), they are rare in open fields here by comparison with other countries, e.g., South America (Ahmad & Lloyd 1972).

The pathogens of *H. arator* were surveyed by Archibald *et al.* (1975), who recorded a small RNA virus, a coccidian protozoan *Adelina* sp., a rickettsia and two species of insect pathogenic fungi. *Adelina* sp., identified by Malone & Dhana (1988) as *A. tenebrionis* Sautet, was the most common pathogen associated with black beetle population declines. King *et al.* (1985) concluded that *Adelina* sp. can have a significant effect on mortality and fecundity, although its influence on the population dynamics of *H. arator* is unclear.

Overseas programmes

The testing of European parasitoids against *H. arator* began in 1967 after several exotic parasitoids which were introduced in the *Costelytra* programme (Chapter 2) did not develop in the New Zealand native scarabaeid, *Costelytra zealandica* (White). D.H. Todd (DSIR files) reported the shipment of *H. arator* larvae from New Zealand to the Biological Control Research Institute at Versailles, France, where tests 'showed promise of control by a dipterous parasite', *Microphthalma europaea* Egger (Tachinidae). R.J.B. Power (DSIR files) recorded that *M. europaea* was commonly reared at Versailles on the scarabaeids *Potosia cuprea* (F.) (Cetoniinae) and *Phyllognathus excavatus* (Förster) (Dynastinae), and confirmed that it was also reared on *H. arator*. Consignments of *M. europaea* were sent to New Zealand from 1967.

Interest in tachinids was continued and focussed on earlier work in South Africa, the original source of *H. arator*. The reports of P. Reynard (1937-1940 unpublished reports), summarised in Harington (1953), indicated a mean parasitism of 34% by *Microphthalma capensis* Schiner, now *M. sejuncta* Walker, in the Cape Province. Harington (1953) also reported the occurrence of some pathogens and a hymenopterous scoliid parasitoid. In the summer of 1974-75, W.P. Thomas undertook a survey in South Africa which indicated a range of natural enemies which could be considered for importation (DSIR files). This was followed by a survey and collection trip in South Africa by E.W. Valentine from 1976 to 1978 (Valentine 1979).

Valentine concentrated his work in the southern coast area where the climate best matched that in northern New Zealand, apart from greater extremes of temperature and some long dry periods. The Carabidae and Tiphiidae were considered the best prospects for adaptation to New Zealand conditions. After surveys of Reynard's previous collection sites and his tachinid specimens, Valentine (1979) concluded that the records referred to the dynastine *Temnorhynchus*, parasitised by a different *Microphthalma* species which would be of little use in New Zealand. *Tiphia transvaalensis* (Tiphiidae) was active over a long period and required a succession of hosts, which included ruteline and dynastine scarabaeid larvae. Valentine (1979) recorded variable parasitism up to 64% by *T. transvaalensis*, but considered that its requirement for a series of hosts may limit its prospects for establishment in New Zealand. *Scarites* spp. (Carabidae) were commonly found in stable grassland where adults and larvae burrowed and fed on scarabaeids, weevils, worms, Lepidoptera and probably other prey commonly occurring in the soil. Valentine (1979) considered that *Scarites* spp. were consistently abundant enough to be a significant predator.

Importations, Releases and Recoveries

European programme

Shipments of *M. europaea* from La Minière par Versailles, in 1967 are detailed by D.H. Todd (DSIR files). Parasitoids reared on the cetoniine *Potosia cuprea* and the dynastine *Phyllognathus excavatus* were shipped to Palmerston North between January and April 1967. Seven shipments totalling 10,900 puparia produced 5,877 flies. These were liberated at Opotiki (3,132) and Te Kaha (2,331), in the eastern Bay of Plenty, in fields infested with black beetle larvae. The remainder were released into field cages. Searches in these areas in 1967 and 1968 revealed no adult parasitoids or parasitised black beetle larvae.

A second series of shipments was made in 1969, when a total of 1,698 puparia was sent to R.J.B. Power at Nelson for attempted experimental rearing on the scarabaeid genera; *Odontria*, *Stethaspis*, *Costelytra*, *Pyronota* and *Pericoptus*. Successful development was obtained on the indigenous dynastine *Pericoptus truncatus* (F.), but *M. europaea* was always encapsulated by the melolonthine hosts (DSIR files). No field recoveries of *M. europaea* were reported.

South African programme

Shipments from South Africa were made from 1976 to 1978, as outlined in Cameron *et al.* (1979).

Scoliidae

A trial shipment of 233 scoliid adults in April 1976 consisted of *Cathimeris capensis* (Saussure) and *Micromeriella atropos* (Saussure). Only *M. atropos* included females, and these few died soon after arrival. The surviving 87 males of 233 adults sent were shown to feed on a variety of flowers including clover, fennel, gorse, manuka (*Leptospermum* sp.), and wattle, and lived for an average of 13 days from collection.

Tiphia transvaalensis Cameron (Hymenoptera: Tiphiidae)

T. transvaalensis was received in March 1977 as a small shipment of 16 adults. Five surviving females were used in attempted parasitisation of second and third instar *H. arator*, with no success. A total of 175 cocoons was shipped in March and April 1977, but poor emergence over a protracted interval prevented rearing (Cameron *et al.* 1979).

Dexia uniseta Curran (Diptera: Tachinidae)

A total of 32 *D. uniseta* puparia was shipped in March 1977 and February 1978 and approximately 50% emergence was obtained. No planidia were obtained from the first shipment but a range of 70-119 was obtained from five females in the second shipment. These were used to inoculate 178 *H. arator* larvae with no success. No releases were made (DSIR files).

Scarites spp. (Coleoptera: Carabidae)

Two *Scarites* species collected by Valentine (1979) were shipped from January 1977 to February 1978. The slightly larger species represented 83% of those sent and, as it survived shipment better, the rearing results presented are based on this species. Cameron *et al.* (1979) demonstrated that *Scarites* sp. had a feeding preference for *H. arator* larvae and could consume one large larva per day at prey densities of $50/m^2$. It also attacked other soft-bodied larvae including Noctuidae. Eggs were obtained from October to December at an average of four to eight eggs per female (Entomology Division DSIR 1978, 1979). Development to the adult stage required three to four months, but as only ten pupae and two adults were obtained, mass rearing was not practicable. Imported adults were released after they had been overwintered in quarantine.

In December 1977 a total of 40 adults was released before the peak egg laying period into field cages at Woodhill near Auckland and at the Mt Albert Research Centre (Cameron *et al.* 1979). This was followed by releases of a further 32 adults at Woodhill and 40 at Ruakaka (Northland) in 1978 (Entomology Division DSIR 1979). Recoveries of nine larvae in 1978 and one in 1979 demonstrated the ability of *Scarites* sp. to survive, overwinter and reproduce.

Evaluation

Microphthalma europaea was shown to develop successfully on *H. arator* in the laboratory but as no recoveries were made from the field it had no impact on pest populations.

The recoveries of *Scarites* sp. larvae represent the most encouraging result yet achieved in New Zealand with introductions of ground dwelling general predators. The low reproductive rate of *Scarites* sp., and its adult longevity of at least two years, indicates that if it has survived, population increases would be slow. After dispersal from release areas these

predators would be difficult to detect. The ability of *Scarites* sp. to survive on alternative prey increases its chances of establishment, even during the last few years in New Zealand when *H. arator* populations have declined. At present there is no information to suggest that *Scarites* sp. is established.

Conclusions

Although large releases of *M. europaea* were made against *H. arator*, all the parasitoids were reared on European scarabaeid hosts. The extent of rearing success in the laboratory on *H. arator* appears to have been minor, whereas *Pericoptus truncatus* was a more suitable host and was considered for maintenance of the parasitoid colony in New Zealand (DSIR files). The failure of *M. europaea* to establish may have resulted from its inability to adapt to a new host. Where such an adaptation is required it is possible that very large numbers, e.g. over 30,000 (Beirne 1975), would be required to increase the chances of establishment.

No pathogens have been introduced against *H. arator*, but the infection of this exotic pest by *Adelina tenebrionis* probably represents cross infection from the endemic source in *P. truncatus* (Wigley 1985). This suggests that other useful pathogens may be present in endemic or exotic hosts.

The polyphagous feeding habits of ground dwelling predators have been considered to provide such species with increased adaptability in their establishment phase (Cameron *et al.* 1979). The record in New Zealand, with predators for *C. zealandica* (Chapter 2) and *H. arator*, shows that successful introduction is not straightforward, and there are no similar programmes overseas from which the prospects for establishment can be assessed. Valentine's observations suggest that if *Scarites* sp. were established, it could make a significant contribution to control (Valentine 1979) in New Zealand pasture habitats which at present lack effective predators. The polyphagous habits of *Scarites* sp. also required the estimation of its effects on non-target species such as earthworms (Cameron *et al.* 1979, Valentine 1979). The presentation and discussion of these results led to no objections and, on the basis that no significant risks were present, the project proceeded. As *H. arator* is not currently at outbreak levels the demand for biological control has declined and further introductions are unlikely. Further recovery surveys for *Scarites* sp. would provide valuable information on whether this species has persisted.

Acknowledgements

P.J. Wigley provided valuable comments on the pathogens of *H. arator*.

Literature Cited

Ahmad, R.; Lloyd, D.C. (1972) Studies on the incidence and feeding habits of carabid beetles (Coleoptera: Carabidae) in different habitats in Western Patagonia. *Technical bulletin, Commonwealth Institute of Biological Control* 15, 105-114.

Archibald, R.D.; Longworth, J.F.; King, P.D.; Mercer, C.F. (1975) The effect of two pathogens on a black beetle population in kikuyu pasture. *Proceedings of the 28th New Zealand Weed and Pest Control Conference*, 200-204.

Beirne, B.P. (1975) Biological control attempts by introductions against pest insects in the field in Canada. *Canadian entomologist* 107, 225-236.

Brown, J.G. (1967) Notes and records of New Zealand Scarabaeidae (Coleoptera). *New Zealand entomologist* 3, 42-50.

Butcher, C.F. (1979) *Thyreocephalus orthodoxus* (Coleoptera: Staphylinidae): a general predator found in pastures. Pp. 265-267 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Cameron, P.J.; Butcher, C.F. (1979) Pitfall trapping and soil sampling for Scarabaeidae (Coleoptera) and possible predators in some Northland and Auckland pastures. Pp. 113-117 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Cameron, P.J.; Valentine, E.W.; Butcher, C.F. (1979) Prospects for biological control of pasture Scarabaeidae (Coleoptera) in New Zealand. Pp. 213-216 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Chapman, R.B. (1984) Pasture pests. Pp. 119-142 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

DSIR, Entomology Division, file BC 1/4.

Entomology Division, DSIR, Annual Report 1978.

Entomology Division, DSIR, Annual Report 1979.

Esson, M.J. (1973) Biology and distribution of black beetle (*Heteronychus arator*). *Proceedings of the 26th New Zealand Weed and Pest Control Conference*, 184-188.

Harington, J.S. (1953) Observations on the biology, the parasites and the taxonomic position of the black maize beetle – *Heteronychus sanctae-helenae* BBlanch. *South African journal of science* 50, 11-14.

King, P.D.; Mercer, C.F.; Meekings, J.S. (1981) Ecology of black beetle *Heteronychus arator* (Coleoptera: Scarabaeidae) – Population studies. *New Zealand journal of agricultural research* 24, 87-97.

King, P.D.; Meekings, J.S.; Phillip, K.C. (1985) A protozoan pathogen of black beetle. Pp. 201-209 in Chapman, R.B. (ed.), *Proceedings of the 4th Australasian Conference on Grassland Invertebrate Ecology*. Caxton Press, Christchurch.

Malone, L.A.; Dhana, S. (1988) Life cycle and ultrastructure of *Adelina tenebrionis* (Sporozoa; Adelidae) from *Heteronychus arator* (Coleoptera: Scarabaeidae). *Parasitology research* 74, 201-207.

Todd, D.H. (1959) Black beetle *Heteronychus sanctae-helenae* Blanch, in pastures in New Zealand. *New Zealand journal of agricultural research* 2, 1262-1273.

Valentine, E.W. (1979) The parasites and predators of *Heteronychus arator* in South Africa (Coleoptera: Scarabaeidae). Pp. 216-219 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Watson, R.N. (1979) Dispersal and distribution of *Heteronychus arator* in New Zealand (Coleoptera: Scarabaeidae). Pp. 149-152 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Wigley, P.J. (1985) An evaluation of strategies for using insect pathogens to control pasture pests in New Zealand. Pp. 276-285 in Chapman, R.B. (ed.), *Proceedings of the 4th Australasian Conference on Grassland Invertebrate Ecology*. Caxton Press, Christchurch.

Listronotus bonariensis (Kuschel), Argentine stem weevil (Coleoptera: Curculionidae)

J.J. DYMOCK

Pest Status

Argentine stem weevil (ASW), *Listronotus bonariensis* (Kuschel) (Coleoptera: Curculionidae), is a native of southern South America and was first discovered in New Zealand in 1927. It is a serious pest of pasture and turf grass species, brassica crops and cereals. ASW has two generations each year in New Zealand. Adults lay eggs in leaf sheath tissue in September and October and larvae of this first spring generation are present throughout October and November. After a short pupation period adults emerge in December and lay eggs. Damage from the larvae of this second generation is seen in February and March. Adult feeding is characterised by window-like scars on the leaf blade but it is the larval stage which causes most damage. Tillers eaten by larvae contain frass and die outwards from the innermost leaf which turns brown. This can easily be pulled out due to severance by the larva. In most areas the second generation is more damaging than the first but in Canterbury and drier east coast areas it is the spring generation which is more of a problem. Adults enter a photoperiod-induced reproductive diapause in autumn and overwinter in plant litter at the soil surface (Prestidge *et al.* 1985).

Background

Biological control of ASW was initiated in 1942 when, at the request of Entomology Division, DSIR, an investigation of ASW parasitoids was begun by D.C. Lloyd of the CIBC. He was based in San Carlos de Bariloche in Argentina. In autumn 1942, wheat stalks were collected in Uruguay. Many were attacked by ASW but no parasitoids were found. In spring 1943, more ASW infested wheat stalks were collected but only one weevil was parasitised (Imperial Agricultural Bureaux 1944). The 1944/45 investigations consisted of a survey of the wheat belt of Argentina during spring. Parasitism of ASW was more common in weevils collected from wild grasses. A mymarid, *Anaphes* sp. and undetermined braconids, *Heterospilus* spp., were recorded parasitising up to 25% of ASW eggs and larvae respectively (Imperial Agricultural Bureaux 1945).

This work continued intermittently in conjunction with research on parasitoids of other New Zealand pests (see Chapter 2) but shipments of the ASW egg parasitoid *Anaphes atomarium* (Brèthes) (Hymenoptera: Mymaridae) did not take place until 1966/67 and 1967/68. From 1968-71 research on the alternative hosts of ASW parasitoids continued and there was also work on ASW predators and pathogens (Lloyd & Ahmad 1971, 1972). A study of the biology of the adult parasitoid, *Microctonus hyperodae* Loan (Hymenoptera: Braconidae) was undertaken at San Carlos de Bariloche in 1972/74 (Loan & Lloyd 1974) and in 1973, D.C. Lloyd suggested that *M. hyperodae* would be a good candidate for liberation in New Zealand (DSIR files).

In 1982, biological control of ASW was activated again in New Zealand with the intention of importing *M. hyperodae* from South America. During a vist to Argentina in October 1983, G. Kuschel, Entomology Division, established contacts with the Instituto Nacional de Technologia Agropecuria (INTA) in Castelar, Argentina. They agreed to provide DSIR with parasitised adult ASW. Permits for importation of *M. hyperodae* to New Zealand were issued in 1984 but the project did not proceed (DSIR files).

Parasitoids

Several hymenopteran parasitoids of ASW were found in Argentina (Lloyd & Ahmad 1971). The egg parasitoid *Anaphes atomarium* appeared to be polyphagous, with a good potential rate of increase and was well adapted to a broad range of climatic conditions. The female oviposited in the eggs of its host within the leaf-sheaths of the host plant. Development of the parasitoid from egg to adult was completed in 13-17 days (mean = 15) and a female produced up to 36 offspring (Ahmad 1978). Lloyd & Ahmad (1971) reported up to 19% parasitism of ASW eggs in Argentina.

The larval parasitoids, *Heterospilus* sp. (Hymenoptera: Braconidae) and *Zatropis* sp. (Hymenoptera: Pteromalidae), were thought to be polyphagous but little else is known of their biology (Lloyd & Ahmad 1971).

A parasitoid of adult ASW, *Microctonus hyperodae*, is host specific in Argentina (Loan & Lloyd 1974). Like the weevil, this species is univoltine at San Carlos de Bariloche. One parasitoid larva develops in each weevil and all but the posterior section of the digestive system and some thoracic tissue is consumed before the mature larva emerges. Parasitism reached a maximum of 39% in the field at San Carlos de Bariloche in November (Loan & Lloyd 1974).

Pathogens

Few pathogens have been described from ASW. In Argentina, a nematode species (probably of the family Allantonematidae) has been reported from the haemocoeles of adult weevils and some 'sporozoan' protozoa have been noted in the gut tissue of adults (Lloyd & Ahmad 1972).

These protozoans could be *Microsporidium itiiti* Malone which is common among ASW weevils in New Zealand. This was first tentatively identified as an *Orthosoma* species (Malone *et al.* 1984), but was later shown to be of uncertain generic status and placed in the collective group, *Microsporidium* (Malone 1985a). Laboratory feeding trials using 11 different insect species indicate that this pathogen is probably host-specific to ASW (L.A. Malone pers. comm.). It develops mainly in the midgut tissue of adult weevils and many infective spores are shed with the frass. The primary means of transmission is via contamination of food sources with excreted spores. Transovarial transmission does not occur (Malone 1985b). *M. itiiti* does not kill ASW reared in the laboratory but it reduces the fecundity of adult weevils by shortening the period of egg-laying activity (Malone 1987).

The microsporidian, *Vavraia oncoperae* (Milner & Beaton), commonly found in the pasture pests, grass grub, *Costelytra zealandica* (White) (Coleoptera: Scarabaeidae), and porina, *Wiseana* spp. (Lepidoptera: Hepialidae), may occasionally be found in *L. bonariensis* (Malone *et al.* 1987). Its effects on stem weevils in the field are unknown. In addition, an unidentified *Nosema* species and an unidentified neogregarine protozoan have been noted from *L. bonariensis* adults (Malone *et al.* 1984).

A fungal pathogen, *Beauveria* sp., has been observed infecting adult weevils in Waikato (G.M. Barker & R.P. Pottinger pers. comm.), Palmerston North (D.L. Gaynor pers. comm.) and Canterbury (S.L. Goldson pers. comm.).

No bacterial or viral pathogens have been recorded from this insect.

Predators

Egg predators of ASW observed in Argentina included *Sericophanes obscuricornis* Poppius (Hemiptera: Miridae), *Nabis punctipennis* Blanchard (Hemiptera: Nabidae) and *Philonthus* spp. (Coleoptera: Staphylinidae) (Lloyd & Ahmad 1971). Six carabid species preyed on ASW adults but they were all general predators feeding on a wide range of hosts and had little impact on weevil populations (Lloyd & Ahmad 1971).

Importations, Releases and Recoveries

From November 1966 to January 1967, 17 consignments of *A. atomarium* were sent to New Zealand. Parasitism of the 5,410 ASW eggs sent was 10.2% with 239 males and 288 females emerging. A total of 175 parasitoids produced by these adults was released as larvae, pupae and adults in ASW eggs in ryegrass tiller fragments. Three releases were made at Nelson and one at Lincoln. Parasitoids were also reared in insectaries at Nelson and parasitised ASW eggs were found as late as the first week in April where the last release was in January 1967. Both field and insectary populations failed to overwinter (DSIR files).

A further five consignments of *A. atomarium* in 7,100 ASW eggs were received in December 1967 from Argentina, and 708 males and 862 females emerged (DSIR files). The progeny of these adults were released in the field as pupae in weevil eggs in the Waikato, Nelson and Lincoln in February 1968. These were first and second generation insects reared at Nelson but there is no record of the numbers released. Parasitism reached 74% in insectaries but had ceased by late March (DSIR files). Field releases failed to establish and it was concluded that hosts other than ASW are required to ensure that *A. atomarium* can survive the winter (DSIR files).

ASW parasitised by *Heterospilus* sp. were expected to arrive in New Zealand in January 1966 from collections made by Professor Silveira, a CIBC field agent at San Carlos de Bariloche. Although no *Heterospilus* sp. were received, other parasitoids did emerge from this material. These were described by B.B. Given as 'large numbers of a very slender, pale parasite, a shorter rather darker species and two or possibly three species of chalcidoids'. It was not known whether these parasitised ASW but 'a couple of hundred' of the slender pale species were liberated at Nelson in January 1966 (DSIR files).

Evaluation

Anaphes atomarium was not recovered in the field after the two introductions. Few parasitoids were released but the failure to overwinter was crucial and was attributed to the lack of alternative hosts rather than the small founding population. More information on the biology of *A. atomarium* is needed before any reintroduction can be considered. There is no record of the recovery or establishment of the other hymenopterous species released in January 1966.

Conclusions

Importation of the adult parasitoid *Microctonus hyperodae* from South America is planned for 1988/89. It is hoped that the promising results obtained for *M. aethiopoides* Loan, introduced for biological control of *Sitona discoideus* Gyllenhal in Canterbury (Proffitt & Goldson 1987), may also be obtained for *M. hyperodae* against ASW.

Acknowledgements

I thank Louise Malone, Entomology Division, DSIR for information on ASW pathogens.

Literature Cited

Ahmad, R. (1978) Note on the breeding of the Argentine stem weevil, *Hyperodes bonariensis* (Coleoptera: Curculionidae) and its egg parasite *Patasson atomarius* (Hymenoptera: Mymaridae). *Entomophaga* 23, 161-162.

DSIR, Entomology Division, file BC 1/4.

Imperial Agricultural Bureaux (1944) 15th Annual Report.

Imperial Agricultural Bureaux (1945) 16th Annual Report.

Lloyd, D.C.; Ahmad, R. (1971) Investigations on natural enemies of some pasture and alfalfa insects in Argentina. Commonwealth Institute Biological Control Mimeograph Report, 15 pp.

Lloyd, D.C.; Ahmad, R. (1972) Investigations on natural enemies of some pasture and alfalfa insects in Argentina. Commonwealth Institute of Biological Control Mimeograph Report, 17 pp.

Loan, C.C.; Lloyd, D.C. (1974) Description and field biology of *Microctonus hyperodae* Loan, (Hymenoptera: Braconidae, Euphorinae) a parasite of *Hyperodes bonariensis* in South America (Coleoptera: Curculionidae). *Entomophaga* 19, 7-12.

Malone, L.A. (1985a) A new pathogen, *Microsporidium itiiti* n. sp. (Microsporida), from the Argentine stem weevil, *Listronotus bonariensis* (Coleoptera, Curculionidae). *Journal of protozoology* 32, 535-541.

Malone, L.A. (1985b) Transmission mechanisms of *Microsporidium itiiti*, a protozoan pathogen of the Argentine stem weevil. *Proceedings of the 4th Australasian Conference on Grassland Invertebrate Ecology*, 217- 223.

Malone, L.A. (1987) Longevity and fecundity of Argentine stem weevils, *Listronotus bonariensis* (Coleoptera: Curculionidae), infected with *Microsporidium itiiti* (Protozoa: Microspora). *Journal of invertebrate pathology* 50, 113-117.

Malone, L.A.; Barker, G.M.; Pottinger, R.P. (1984) Some protozoan pathogens of the Argentine stem weevil, *Listronotus bonariensis* (Coleoptera: Curculionidae), in New Zealand. *New Zealand entomologist* 8, 124-127.

Malone, L.A.; Wigley, P.J.; Dhana, S.D. (1987) Identity of a microsporidium from three New Zealand pasture insects: *Costelytra zealandica* (Coleoptera, Scarabaeidae), *Wiseana* spp. (Lepidoptera, Hepialidae), and *Listronotus bonariensis* (Coleptera, Curculionidae). *Journal of invertebrate pathology* 49, 135-1443.

Prestidge, R.A.; Pottinger, R.P.; Barker, G.M. (1985) Argentine stem weevil, biology, damage and control. *Aglink* FPP 48.

Proffitt, J.R.; Goldson, S.L. (1987) Overwintering biology and survival of the Sitona weevil parasitoid, *Microctonus aethiopoides*. *Proceedings of the 40th New Zealand Weed and Pest Control Conference*, 31-32.

Sitona discoideus Gyllenhal, sitona weevil (Coleoptera: Curculionidae)

M.W. STUFKENS and J.A. FARRELL

Pest Status

Sitona discoideus Gyllenhal, sitona weevil, first appeared in New Zealand in 1974 (Esson 1975) and is now found throughout New Zealand on lucerne and medics (*Medicago* spp.) which comprise the host range of the species. Adult feeding causes some defoliation in lucerne crops, but feeding damage by up to 4,000 larvae/m^2 causes up to 50% loss of forage yield (Goldson *et al.* 1985, S.L Goldson unpublished).

The life cycle is univoltine. Adults emerge from pupae in the soil during December and January. After feeding on *Medicago* spp. foliage, adults fly to aestivation sites, at the base of trees, hedgerows and fence-posts, in January. Return flights to *Medicago* spp. are made in late March to mid May, followed by oviposition in autumn and spring. The larvae feed on root nodules and root hairs before pupation in December. Fenitrothion (0.6 kg a.i./ha) is used extensively for *S. discoideus* control in lucerne crops, and the pest is considered to be an important factor limiting lucerne production (S.L. Goldson pers. comm.).

Background

There is little information on natural enemies of *S. discoideus* in New Zealand. Wood (1980) reported a protozoan infection (*Pleistophora* sp.) and predation on adults by starlings. Wightman (1986) reported occasional parasitism of adults by *Dinocampus* (= *Perilitus*) *coccinellae* (Schrank) (Hymenoptera: Braconidae), a parasitoid of the ladybird (*Coccinella undecimpunctata* L.). The introduction of a more effective parasitoid of *S. discoideus* was planned by Entomology Division in 1982. Aeschlimann (1978) reported substantial parasitism of adult *S. discoideus* by *Microctonus aethiopoides* Loan (Hymenoptera: Braconidae) in Morocco.

This parasitoid was imported into Australia in 1976 as a biological control agent against *S. discoideus* (Cullen & Hopkins 1982). *M. aethiopoides* was therefore chosen for importation and release in New Zealand (Wightman 1986).

Importations, Releases and Recoveries

A shipment of 317 *Microctonus aethiopoides* pupae from New South Wales was received at the Lincoln quarantine laboratory in May 1982. *M. aethiopoides* was reared through four generations in the laboratory, using *S. discoideus* fed on potted lucerne as hosts.

Material for release consisted of parasitised adult *S. discoideus* (93%) or adult *M. aethiopoides* (7%). Releases were made between October 1982 and June 1985 at 17 sites: Central Otago (one site), Canterbury (13 sites) and Marlborough (three sites) in the South Island. Sites chosen were lucerne crops infested with *S. discoideus*, on which released material was caged for one month before removal of cages (0.5 m^2). Approximate numbers of *M. aethiopoides* released in Otago (3,990), mid-Canterbury (18,670), North Canterbury (5,080) and Marlborough (5,100) totalled 32,840 (Stufkens *et al.* 1987).

Recoveries were made during surveys of 110 South Island lucerne crops in April-June 1985, April-June 1986 and November 1986. Sitona weevils were collected from foliage by sweep-net. In 1985, 100 adults were held in the laboratory for one month for parasitoid emergence. In 1986, 25-50 adults were dissected to record parasitoid larvae. Release sites were sampled for recovery at least one year after release. *M. aethiopoides* was found at 90 sites (82%), and 24% of the adult *S. discoideus* (total 3,232) collected at these sites were parasitised (Stufkens *et al.* 1987).

Evaluation

Goldson & Proffitt (1986) recorded *M. aethiopoides* from 40-55% of *S. discoideus* collected in weekly samples between April and June 1986 at a site in mid-Canterbury. This rate of parasitism is comparable with that recorded in Morocco by Aeschlimann (1978). However, Goldson & Proffitt (1986) point out that mortality due to parasitism in *S. discoideus* occurs before the strongly density-dependent mortality of larvae during their establishment in lucerne root nodules. Compensatory reduction in larval mortality may thus follow adult mortality.

Conclusions

Microctonus aethiopoides is successfully established as a natural enemy of *S. discoideus* in the South Island of New Zealand. Further studies on *S. discoideus* population dynamics are needed to quantify the impact of *M. aethiopoides*.

Acknowledgements

To J.A. Wightman and S.L. Goldson for valuable discussion.

Literature Cited

Aeschlimann, J.-P. (1978) Heavy infestations of *S. discoideus* (Col., Curc.) on lucerne in southern Morocco. *Annales de zoologie et ecologie animale* 10, 221-225.

Cullen, J.M.; Hopkins, D.C. (1982) Rearing, release and recovery of *Microctonus aethiopoides* Loan (Hymenoptera: Braconidae) imported for the control of *Sitona discoideus* Gyllenhal (Coleoptera: Curculionidae) in south-eastern Australia. *Journal of the Australian Entomological Society* 1, 279-284.

Esson, M.J. (1975) Notes on the biology and distribution of three recently-discovered exotic weevil pests in Hawkes Bay. *Proceedings of the 28th New Zealand Weed and Pest Control Conference*, 208-212.

Goldson, S.L.; Proffitt, J.R. (1986) The seasonal behaviour of the parasite *Microctonus aethiopoides* and its effects on sitona weevil. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 122-125.

Goldson, S.L.; Dyson, C.B.; Proffitt, J.R.; Frampton, E.R.; Logan, J.A. (1985) The effect of *S. discoideus* Gyllenhal (Coleoptera: Curculionidae) on lucerne yields in New Zealand. *Bulletin of entomological research* 75, 429-442.

Stufkens, M.W.; Farrell, J.A.; Goldson, S.L. (1987) Establishment of *Microctonus aethiopoides*, a parasitoid of the sitona weevil, in New Zealand. *Proceedings of the 40th New Zealand Weed and Pest Control Conference*, 31-32.

Wightman, J.A. (1986) *S. discoideus* (Coleoptera: Curculionidae) in New Zealand, 1975-1983; distribution, population studies, and bionomic strategy. *New Zealand journal of zoology* 13, 221-240.

Wood, J.A. (1980) Notes on the sitona weevil (*Sitona humeralis*) (Coleoptera: Curculionidae), a pest of lucerne in Canterbury. *New Zealand entomologist* 7, 169-171.

Sminthurus viridis (L.), lucerne flea (Collembola: Sminthuridae)

P.R. DENTENER and J. EDWARDS

Pest Status

Sminthurus viridis (L.) (= *Smynthurus viridis* (L.)) originates from Europe where it is present in most countries (Anonymous 1956). It is also found in South Africa, Australia and New Zealand (Wallace 1974b) where it was possibly introduced as aestivating eggs on soil or seeds (Dumbleton 1938, Walters 1964).

Whereas most Collembola species are harmless and even beneficial for the structure of the soil (Rusek 1975), the lucerne flea (or clover springtail) attacks a wide range of host plants. Lucerne and clover are the preferred hosts (Walters 1964). Damage is done by chiselling and biting the plant tissue and heavy attacks can give the leaves a skeletonised appearance. Damage to clover not only reduces yield, but repels cattle and sheep, which refuse to eat pasture fouled by lucerne flea faeces (Pottinger 1983).

Although lucerne flea is known to feed on crop plants, it is not considered a pest in Europe (Maclagan 1932). However, it is a pest in Australia (Wallace 1954), and in South Africa it infested more than 50,000 ha in 1959 (Wallace & Walters 1974). In New Zealand, lucerne flea is found in isolated patches in the North and the South Islands (Dumbleton 1938). Until 1982 lucerne flea was recognised as a pest of localised importance only in the North Waikato. Since then, however, damage on farms in the Kaipara and Manukau Harbour areas, Te Kauwhata, Huntly and Morrinsville has increased its pest status. High population densities in experimental plots have caused maximum losses of up to 20% in pasture production (Dentener 1985, Pottinger 1983).

Background

Predators

A wide variety of insects prey on lucerne flea but bdellid mites are considered the most important predators (Wallace 1967, 1974b). The presence of one bdellid mite species, *Bdellodes lapidaria* (Kramer) (= *Biscirus lapidarius* Kramer) in New Zealand was recorded by Davies (1928) and confirmed by Dumbleton (1938) but only low numbers were found. Recently (Dentener 1985, R.P. Pottinger pers. comm.) *B. lapidaria* has been found in the South Auckland/Waikato area but no effect on lucerne flea populations was noted.

This is in contrast to the control success achieved in some areas such as Western Australia where the mite occurred naturally and considerably restricted lucerne flea population increases (Wallace 1954, 1967). In areas where the predator was present minor outbreaks occurred once in every three to five years, but in areas where the predator was absent substantial outbreaks could be expected nearly every year. Wallace (1967) found, however, that *Bdellodes lapidaria* did not have the same distribution in Western Australia as *S. viridis*, the latter penetrating further into dry regions. This allowed population build-up of lucerne flea in areas where it was not controlled by bdellid mites.

Bdellid mites were collected from Western Australia and distributed throughout south-western Australia, Victoria and Tasmania (Currie 1934). Transportation was discontinued when it was found that mites were already present in many localities removed from release sites. Subsequent collections confirmed the establishment of bdellid mites in these areas (Wallace & Mahon 1971). Collections in Tasmania showed that *B. lapidaria* was found only in a restricted area (Ireson 1984).

In a survey of predatory mites in Europe (Wallace 1974a) another bdellid mite, *Neomolgus capillatus* (Kramer), was commonly found feeding on lucerne flea in pastures. The fact that it could tolerate even the driest areas examined in Spain and Morocco indicated that it should be capable of establishing throughout the full range of its prey in Australia.

In 1965 Wallace collected *N. capillatus* from the Netherlands and introduced it into Western Australia. The mite did not establish and it was assumed that the reason for this was the lack of adaptability by the mites necessary to ensure survival over the long, dry summer period (Wallace 1974a). A second collection was made in 1969 in Morocco because it was assumed that material better adapted to the Western Australian climate could be obtained there. *N. capillatus* was introduced into Australia and is now well established. It is capable of a substantial control of lucerne flea but its rate of spread is extremely slow (Wallace 1981).

Between 1963 and 1966 large numbers of *B. lapidaria* were collected in Western Australia and sent to selected sites in South Africa. The mites were shown to be established in 1965 and multiplied rapidly, enabling redistribution to additional sites (Wallace & Walters 1974).

Introduction of *B. lapidaria* alone in the Afrotropical region in 1963 was considered to be insufficient to control lucerne flea, but a more recent introduction of *N. capillatus* showed promise of permanent establishment (Greathead 1971).

In Tasmania *B. lapidaria* does not exert control on lucerne flea (Ireson 1982). *B. lapidaria* is a non-selective predator which is able to maintain itself on other prey species during adverse periods, whilst still maintaining a useful control of the main prey species (Wallace & Walters 1974). In Tasmania the seasonality and abundance of alternative prey species may cause the predation effectiveness of *B. lapidaria* on *S. viridis* to be reduced (Ireson 1984).

Parasitoids

Ireson & Miller (1983) described laboratory trials in which lucerne flea were infected with insect parasitic nematodes *Steinernema bibionis* (Bovien) and *Heterorhabditis heliothidis* (Khan, Brooks & Hirschmann). A high level of parasitism was observed in these experiments and application of the nematodes significantly increased lucerne flea mortality.

Importations, Releases and Recoveries

In 1938, Dumbleton (1938) mentioned that *B. lapidaria* was already present in New Zealand. He also reported the collection of *B. lapidaria* in Western Australia for shipment to New Zealand for experimental release at Maraekakaho (Hawke's Bay). This site was chosen because lucerne flea was abundant and no mites were present. Two consignments of *B. lapidaria* arrived in New Zealand in 1938 but in both cases the mites did not survive the trip (DSIR files). No further mention of release, establishment and recovery of the bdellid mite is made in the literature. However, a recent survey of some farms in the area showed that the mite was present in very low numbers (J. Edwards unpublished data).

Evaluation

The presence of *B. lapidaria* in New Zealand was confirmed by Dumbleton (1938) who noted that the mites were present in low numbers and only in areas with high and evenly distributed rainfall. An experimental release of the mites was planned but eventually did not take place. No further reference has been published with respect to establishment or recovery of the bdellid mite.

Dentener (1985) mentioned the presence of *B. lapidaria* in research plots on a farm property near Huntly. The mites were present in such low numbers that no control effect on lucerne flea, or Symphypleona in general, could be attributed to the predatory mite. Research carried out by J. Edwards (unpublished) has shown the presence of *B. lapidaria*

at Ruakura Agricultural Research Centre (Ministry of Agriculture & Fisheries, Hamilton) but only low numbers were found.

It is difficult to attribute failure by the mite to establish control of lucerne flea populations in those areas surveyed in New Zealand to any factor. It has been shown by Wallace (1981) that establishment of bdellid mites and their use for control of lucerne flea may take up to 10 years. It is possible that *B. lapidaria* is not a suitable predator of lucerne flea under New Zealand climatic conditions. It seems that introduction of *N. capillatus* alone or in combination with *B. lapidaria* may have a greater effect in controlling lucerne flea populations. Also, the application of insecticide sprays may have played a role in reducing the number of mites, and thereby influenced their control on lucerne flea populations.

Conclusions

At the moment *B. lapidaria* does not successfully control lucerne flea populations in New Zealand. In order to explain this there should be further studies of the mite biology and ecology. Additional predators or parasitoids (such as nematodes) that are potentially able to control lucerne flea could also be screened. Introduction of *N. capillatus* from a climatically similar region into New Zealand for experimental purposes to study establishment and recovery is strongly recommended. Until biological control measures have been established, monitored spraying of lucerne flea populations combined with grazing management, as described by Pottinger *et al.* (1985), is recommended for control. It is vital to establish a spray programme containing nonacaricidal insecticides if predatory mite numbers are not to be affected.

Literature Cited

Anonymous (1956) Distribution maps of insect pests. Pest: *Sminthurus viridis*. Series A, map 63. Commonwealth Institute of Entomology, London.

Currie, G.A. (1934) The bdellid mite, *Biscirus lapidarius* Kramer, predatory on the lucerne flea *Sminthurus viridis* L. in Western Australia. *Journal of the Council for Scientific and Industrial Research Australia* 7, 9-20.

Davies, W.M. (1928) On the economic status and bionomics of *Sminthurus viridis*. *Bulletin of entomological research* 18, 291.

Dentener, P.R. (1985) The ecology of the lucerne flea, *Sminthurus viridis*, in the South-Auckland/Waikato area. Ph.D. thesis, Waikato University, New Zealand, 289 pp.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1938) The lucerne flea (*Smynthurus viridis*) in New Zealand. *New Zealand journal of science and technology* 20A, 197-211.

Greathead, D.J. (1971) A review of biological control in the Ethiopian region. *Technical Communication, Commonwealth Institute of Biological Control* 5, 162 pp.

Ireson, J.E. (1982) A re-examination of the distribution of the pasture snout mite, *Bdellodes lapidaria* (Kramer) (Acari: Bdellidae) and the lucerne flea *Sminthurus viridis* (L.) (Collembola: Sminthuridae) in Tasmania. *Journal of the Australian Entomological Society* 21, 251-255.

Ireson, J.E. (1984) The effectiveness of *Bdellodes lapidaria* (Kramer) (Acari: Bdellidae) as a predator of *Sminthurus viridis* (L.) (Collembola: Sminthuridae) in north west Tasmania. *Journal of the Australian Entomological Society* 23, 185-191.

Ireson, J.E.; Miller, L.A. (1983) Susceptibility of the collembolan *Sminthurus viridis* to the insect parasitic nematodes *Neoaplectana bibionis* and *Heterorhabditis heliothidis*. *Entomologia experimentalis et applicata* 34, 342-343.

Maclagan, D.S. (1932) An ecological study of the 'lucerne flea' (*Smynthurus viridis*, Linn.). II. *Bulletin of entomological research* 23, 151-190.

Pottinger, R.P. (1983) Recent developments with pasture pests. *Proceedings 35th Ruakura Farmers' Conference*, 99-105.

Pottinger, R.P.; Wrenn, N.R.; McGhie, R.A. (1985) Timing treatments for control of lucerne flea (*Sminthurus viridis*) in northern North Island pastures. Pp. 133-140 in Chapman, R.B. (ed.), *Proceedings 4th Australasian Conference on Grassland Invertebrate Ecology*. Caxton Press, Christchurch.

Rusek, J. (1975) Die bodenbildende Funktion von Collembolen und Acarina. *Pedobiologia* 15, 299-308.

Wallace, M.M.H. (1954) The effect of DDT and BHC on the population of the lucerne flea, *Sminthurus viridis* (L.) (Collembola) and its control by predatory mites, *Biscirus* spp. (Bdellidae). *Australian journal of agricultural research* 5, 148-155.

Wallace, M.M.H. (1967) The ecology of *Sminthurus viridis* (L.) (Collembola). I. Processes influencing numbers in pastures in Western Australia. *Australian journal of zoology* 15, 1173-1206.

Wallace, M.M.H. (1974a) An attempt to extend the biological control of *Sminthurus viridis* (Collembola) to new areas in Australia by introducing a predatory mite, *Neomolgus capillatus* (Bdellidae). *Australian journal of zoology* 22, 519-529.

Wallace, M.M.H. (1974b) Present and probable world distribution of *Sminthurus viridis* and prospects for its biological control. *Pedobiologia* 14, 238-243.

Wallace, M.M.H. (1981) Tackling the lucerne flea and red-legged earth mite. *Journal of agriculture of Western Australia* 22(2), 72-74.

Wallace, M.M.H.; Mahon, J.A. (1971) The ecology of *Sminthurus viridis* (Collembola). III. The influence of climate and land use on its distribution and that of an important predator, *Bdellodes lapidaria* (Acari: Bdellidae). *Australian journal of zoology* 19, 177-188.

Wallace, M.M.H.; Walters, M.C. (1974) The introduction of *Bdellodes lapidaria* (Acari: Bdellidae) from Australia into South Africa for the biological control of *Sminthurus viridis* (Collembola). *Australian journal of zoology* 22, 505-517.

Walters, M.C. (1964) A study of *Sminthurus viridis* (L.) (Collembola) in the Western Cape Province. *Department of Agriculture, Technical Services and Entomology*, Memoirs 16 (South Africa), 1-99.

Therioaphis trifolii (Monell) forma *maculata* (Buckton), spotted alfalfa aphid (Homoptera: Aphididae)

G.P. WALKER and P.J. CAMERON

Pest Status

The spotted alfalfa aphid (SAA), *Therioaphis trifolii* (Monell) forma *maculata* (Buckton), was first recorded in New Zealand at Pukekohe, South Auckland in April 1982, and by May was found to be distributed throughout most of the greater Auckland region. Although *Medicago* spp., especially lucerne (*M. sativa*) and some medics, supported the highest populations, substantial numbers were also found on white clover, *Trifolium repens* (Cameron *et al.* 1983b). From November 1982 SAA was present on lucerne at Pukekohe but populations did not increase significantly until February 1983, peaking at 25 per stem. Populations in the Auckland area have since declined each year, with minor population increases on lucerne occurring in late summer and autumn (Cameron & Walker 1984). SAA was recorded in Hawke's Bay and North Canterbury in 1984 (Entomology Division DSIR 1985), but no outbreaks have been reported.

In many lucerne growing areas overseas, SAA is the most damaging lucerne aphid, partly because it prefers the hot and dry conditions (Nielson & Barnes 1961) where lucerne is often grown. The temperate New Zealand climate is not as favourable for SAA development and *Acyrthosiphon* spp. still dominate the lucerne aphid fauna (Cameron & Walker 1984). Whereas climate has limited SAA population increases in New Zealand, the occurrence of sexual forms (Walker & Cameron 1985) indicates that SAA is capable of persisting in areas with cool winters.

At moderate population levels (less than 100 per stem) SAA can cause severe yield losses and shortening of the life of susceptible lucerne cultivars (Marble 1978). SAA caused millions of dollars worth of damage to the then non-resistant lucerne crops of the U.S.A. (Burkhardt 1959) and Australia (Lehane 1982) after spreading to these countries in 1953 and 1977 respectively. In New Zealand we have observed SAA populations which have caused minor leaf abscission, but no plant deaths or commercial damage have been reported.

Background

Spotted alfalfa aphid was discovered in New Zealand five years after it first occurred in Australia and seven years after the arrival of blue green lucerne aphid (BGA), *Acyrthosiphon kondoi* Shinji in New Zealand. In this interval the existing natural enemy fauna of lucerne aphids was examined (Cameron *et al.* 1979, Thomas 1977) while lucerne cultivars with resistance to SAA and *Acyrthosiphon pisum* Harris were imported and BGA resistance developed (Dunbier & Easton 1982). SAA has become an additional prey of the main lucerne aphid predators identified in these studies. These predators include *Micromus tasmaniae* (Walker) (Hemerobiidae), *Nabis capsiformis* Germar (Nabidae), *Coccinella undecimpunctata* L. (Coccinellidae), *Melanostoma fasciatum* (Macquart) (Syrphidae), and various spiders. *Micromus tasmaniae* may be the most effective predator of lucerne aphids including SAA because it is more abundant than other predators (Entomology Division, DSIR 1984) and better synchronised with aphid populations (Cameron *et al.* 1983a). In South Australia, predation by *M. tasmaniae* and spiders appears to reduce SAA numbers in the spring (Allen 1986). By comparison with Australia and California, the New Zealand fauna of lucerne

aphid predators is relatively sparse, and further introductions have been attempted. These are considered separately in Chapter 11, which deals with importations of general aphid predators.

SAA and *Acyrthosiphon* spp. were regularly monitored at Pukekohe from 1982 to 1985. Sampling was carried out weekly (four to six occasions between each harvest) using stem, sweep or suction samples (Cameron & Walker 1984), and when sufficient SAA were available 30-100 were reared on lucerne stems to detect parasitoids or pathogens. Prior to introductions, *Aphelinus abdominalis* (Dalman) (Aphelinidae) was the only naturally occurring parasitoid (Walker & Cameron unpublished). This was reared on one to three occasions per season from SAA and more frequently from *Acyrthosiphon* spp. Three species of parasitoids occur on SAA in North America, all introduced from the Mediterranean and Middle East (van den Bosch *et al.* 1964). *Trioxys complanatus* Quilis (Aphidiidae) is the most effective parasitoid in California, and was introduced into Australia in 1977 (Wilson *et al.* 1982) where it became widely established.

Fungal diseases were uncommon at Pukekohe, but two species, *Zoophthora phalloides* Batko and *Entomopthora planchoniana* Cornu were identified (Cameron unpublished). However, most of the fungal pathogens recorded from SAA in Australia by Milner *et al.* (1980) are also present on *Acyrthosiphon* spp. in New Zealand (Cameron & Milner 1981).

The use of resistant cultivars has been the basis for control of SAA in North America and Australia. In New Zealand, resistance was available in several imported and one locally bred cultivar by 1981 (Dunbier & Easton 1982). The resistance of these cultivars to SAA in New Zealand was confirmed soon after the arrival of SAA (Cameron *et al.* 1983b) and further cultivars have since been developed (Easton & Cornege 1984).

Importations, Releases and Recoveries

Six shipments, each of 200-300 *T. complanatus* were received from CSIRO (Canberra and Melbourne) from 6 May 1982 to 9 April 1984 (DSIR files). Over 50,000 parasitoids were reared and released into SAA infested lucerne, mainly in the Auckland area, with small releases in the Waikato, Bay of Plenty and Hawke's Bay (Table 7.1).

Table 7.1 Releases and recovery dates for *Trioxys complanatus*

Area Site	No. released	Dates released	Dates recovered
AUCKLAND			
Tapora	5000	Mar. 1983 – Apr. 1983	Apr. 1983 – Nov. 1983
Helensville	13500	Jan. 1983 – Mar. 1983	Apr. 1983 – May 1983
Mt Albert	6200	Dec. 1982 – Mar. 1983	
Whitford	1300	Mar. 1983 – Apr. 1983	
Pukekohe	19000	May 1982 – Apr. 1983	Jan. 1983 – Apr. 1985
WAIKATO			
Huntly	1500	Apr. 1984	
Hamilton	1600	Mar. 1983	
BAY OF PLENTY			
Te Puke	2000	Apr. 1984	
HAWKE'S BAY			
Hastings	170	Mar. 1985	
Total	50270		

Recoveries were made from the major lucerne release site at Pukekohe in January 1983. Six weeks later recoveries were made from adjacent white clover, and in late March the parasitoid was present in lucerne 1 km from the original release site. *T. complanatus* was also recovered in late April at the Helensville release site where 26% parasitism was recorded. A small number of recoveries were also made at a Tapora release site (Wellsford area) in April 1983 and one recovery was made there the next spring. A hyperparasitoid, *Dendrocerus aphidum* (Rondani) (Megaspilidae), was reared from parasitised SAA collected in the field at both Pukekohe and Helensville. Hyperparasitism levels were variable but reached 70%.

Table 7.2 Incidence of spotted alfalfa aphid and percent parasitism by *Trioxys complanatus* on Pukekohe lucerne. Based on 4-6 samples per harvest interval.

Year	Harvest interval	SAA per stem Peak No.	Parasitism Average (%)	Parasitism Aphids reared (No.)
1982/83	1	0.03	–	0
	2	0.4	–	0
	3	24.9	2.0	600
	4	1.3	1.5	200
1983/84	1	0.2	32.4	310
	2	0.4	1.0	400
	3	0.5	2.7	600
	4	3.9	18.0	220
	5	0.3	30.0	40
1984/85	1	0.07	–	0
	2	0	0	81
	3	0.03	0	44
	4	2.8	4.2	900
	5	0.2	11.5	200
1985/86	1	0	–	0
	2	0.03	0	63
	3	0.03	0	200
	4	0	0	74

T. complanatus overwintered successfully at Pukekohe. Parasitism levels averaged 16% during the 1983/84 season, peaking at 38% in March, with host aphid numbers reaching four per stem in autumn (Table 7.2). *T. complanatus* was present at Pukekohe until April 1985 after which SAA numbers fell to such a low level that the parasitoid could not be detected. Extensive surveys from 1983-85 failed to recover *T. complanatus* from other areas in which it was released.

Evaluation

T. complanatus became established in a small area at Pukekohe where it was monitored over three seasons from January 1983 to April 1985. During this time SAA populations declined steadily from year to year. Any small population increases of SAA were restricted to the late summer or autumn when the temperature accumulation between lucerne harvests was sufficient for more than three generations to develop (Cameron & Walker 1984). Cool or wet periods caused population declines. The natural spread of SAA through New Zealand has also been confined to the warmest, driest areas and this may have limited the potential

for *T. complanatus* to spread. Both these patterns show that SAA populations are severely limited by the temperate climate in New Zealand. This may have been accentuated in New Zealand where we have shown (Walker & Cameron 1985) that SAA has a higher development threshold temperature than in Australia or North America.

Against the background of a small and declining population of SAA it is difficult to evaluate the impact of *T. complanatus*. The rates of parasitism recorded at Pukekohe during the spring and late autumn harvest intervals of the 1983/84 season averaged 30% and over, and showed that *T. complanatus* persisted well despite low populations of SAA (Table 7.2). These rates of parasitism are similar to those reported by Wilson *et al.* (1982) in the first year they released *T. complanatus* in South Australia. The decline in parasitism in subsequent years appears to be related to decreasing SAA populations, with minor occurrences of *T. complanatus* confined to late summer. If *T. complanatus* persists in New Zealand it may help limit any subsequent population increases of SAA.

Conclusions

T. complanatus has not been recovered since April 1985 but may still persist at very low levels. With the widespread use of resistant cultivars and the failure of SAA to have any significant impact on New Zealand agriculture, no other biological control strategies appear necessary.

Literature Cited

Allen, P.G. (1984) The impact of predators on spotted alfalfa aphid in lucerne pasture during spring in South Australia. Pp. 375-380 in Hodek, I. (ed.), Ecology of Aphidophaga 2. Academia, Praha.

Burkhardt, C.C. (1959) Effects of heavy fall infestations of spotted alfalfa aphids on subsequent spring growth on alfalfa in Kansas. *Journal of economic entomology* 52, 642-643.

Cameron, P.J.; Milner, R.J. (1981) Incidence of *Entomophthora* spp. in sympatric populations of *Acyrthosiphon kondoi* and *A. pisum*. *New Zealand journal of zoology* 8, 441-446.

Cameron, P.J.; Walker, G.P. (1984) Phenology and host preference of spotted alfalfa aphid on lucerne and white clover. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 77-81.

Cameron, P.J.; Thomas, W.P.; Hill, R.L. (1979) Introduction of lucerne aphid parasites and a preliminary evaluation of the natural enemies of *Acyrthosiphon* spp. (Hemiptera: Aphididae) in New Zealand. Pp. 219-223 in Crosby, T.K.; Pottinger, R.P. (eds) *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*. Government Printer, Wellington.

Cameron, P.J.; Allan, D.J.; Walker, G.P.; Wightman, J.A. (1983a) Management experiments on aphids (*Acyrthosiphon* spp.) and beneficial insects in lucerne. *New Zealand journal of experimental agriculture* 11, 343-349.

Cameron, P.J.; Sunde, R.G.; Walker, G.P. (1983b) Discovery, identification, and host plant interaction of spotted alfalfa aphid (Hemiptera: Aphididae) in New Zealand. *New Zealand journal of experimental agriculture* 26, 511-518.

DSIR, Entomology Division file BC 1/4.

Dunbier, M.W.; Easton, H.S. (1982) Longer stand life with new cultivars. Pp. 121-126 in Wynn-Williams, R.B. (ed.), Lucerne for the 80's. *Agronomy Society of New Zealand Special Publication* 1.

Easton, H.S.; Cornege, E. (1984) 'Grasslands Oranga' lucerne (*Medicago sativa*). *New Zealand journal of experimental agriculture* 12, 283-286.

Entomology Division DSIR (1984) Annual Report, 18-19.

Entomology Division DSIR (1985) Annual Report, 20.

Lehane, L. (1982) Biological control of lucerne aphids. *Commonwealth Scientific Industrial Research Organisation rural research* 114, 4-10.

Marble, V.L. (1978) Lucerne aphids .... a worldwide threat. *World farming* 20(5), 10-11 & 24-26.

Milner, R.J.; Teakle, R.E.; Lutton, G.G.; Dare, F.M. (1980) Pathogens (Phycomycetes: Entomophthoraceae) of the blue green aphid *Acyrthosiphon kondoi* Shinji and other aphids in Australia. *Australian journal of botany* 28, 601-619.

Neilson, M.W.; Barnes, O.L. (1961) Population studies of the spotted alfalfa aphid in Arizona in relation to temperature and rainfall. *Annals of the Entomological Society of America* 54, 441-448.

Thomas, W.P. (1977) Biological control of the blue-green lucerne aphid. The Canterbury situation. *Proceedings of the 30th New Zealand Weed and Pest Control Conference*, 182-187.

Van den Bosch, R.; Schlinger, E.I.; Dietrich, E.J.; Hall, I.M.; Puttler, B. (1964) Studies on succession, distribution, and phenology of imported parasites of *Therioaphis trifolii* (Monell) in southern California. *Ecology* 45, 602-621.

Walker, G.P.; Cameron, P.J. (1985) Temperature responses and the occurrence of sexual forms of spotted alfalfa aphid (Hemiptera: Aphididae) in New Zealand. *New Zealand journal of experimental agriculture* 28, 555-558.

Wilson, C.G.; Swincer, D.E.; Walden, K.J. (1982) The introduction of *Trioxys complanatus* Quilis (Hymenoptera: Aphididae), an internal parasite of the spotted alfalfa aphid, into South Australia. *Journal of the Australian Entomological Society* 21, 13-27.

Wiseana spp., porina (Lepidoptera: Hepialidae)

P.J. CAMERON

Pest Status

Wiseana spp., commonly referred to as porina, are native insects represented by a number of species of which *W. cervinata* (Walker) is the most widespread and common. Porina is a major pasture pest which is distributed throughout New Zealand but is traditionally a problem in the southern North Island and the South Island. Chapman (1984) describes the distribution, biology and importance of the four main species. *W. cervinata* has its peak flight period in mid October, and causes larval damage to pasture in autumn and early winter. *W. despecta* (Walker) flies later in summer and is a wetland species which damages pasture in winter and early spring. *W. signata* (Walker) and *W. umbraculata* (Guénée) are generally restricted to wet areas and are less common species.

Adult *W. cervinata* scatter eggs on the surface of pastures in October and November, and the young larvae develop beneath surface vegetation or in the top soil surface layer in December and January. During this period, larvae are susceptible to surface foraging predators as well as desiccation. Larger larvae construct vertical tunnels from which they emerge nocturnally to feed on surface herbage. These large larvae and pupae are relatively well protected from parasitoids. The main plant hosts are pasture grasses, clovers and lucerne. Damage to tussocks and pampas, and rarely barley and potatoes, has been recorded (Perrott 1974).

Porina damage thresholds for the South Island are considered to be 20-40 larvae/m^2 depending on soil and pasture conditions (Savage & French 1981). Populations vary greatly from year to year and can reach levels of 200 mature larvae/m^2 which cause open patches in pasture and permanent changes in plant species composition. East & Pottinger (1984) rank porina as a pasture pest of national importance.

Background

The most commonly occurring parasitoids of *W. cervinata* found by Eyles (1965) were the tachinids *Pales usitata* Hutton and *Hexamera alcis* (Walker), and the ichneumonid *Ichneumon lotatorius* F., which together accounted for 39% parasitism. Dumbleton (1945) noted that *H. alcis* was the most commonly occurring parasitoid of *Wiseana* spp. and observed higher rates of parasitism in areas near trees. Eyles (1965) also recorded parasitism by *Occisor versutus* Hutton and *Plagiomyia* sp. (Tachinidae), and, in addition, Gourlay (1930) recorded *Lissopimpla excelsa* (Costa) and *Degithina decepta* (Smith) (Ichneumonidae). Valentine (1967) provides full literature records of parasitism by these species. There are few records of predation on *Wiseana* spp. Dumbleton (1945) noted predation by birds, and Eyles (1966) found that the staphylinid *Thyreocephalus chloropterus* (Erichson) occurred with *Wiseana* spp. in pasture and contributed to a reduction in larvae. Both Dumbleton (1945) and Eyles (1966) considered that natural enemies do not effectively control *Wiseana* spp. in pasture, and suggested that the preference of tachinids for sheltered areas limited their impact on this pest in post European improved pasture.

Recently there has been more emphasis on the study of native nematodes and pathogens. The indigenous parasitic nematode *Steinernema bibionis* (Bovien) commonly causes low levels of mortality in *Wiseana* spp. in the southern North Island (Kain *et al.* 1981), and when

artificially applied can give short term control of small larvae in appropriate soil conditions (van der Mespel *et al.* 1986). Nuclear polyhedrosis virus (NPV) has been observed to produce epizootics which Crawford & Kalmakoff (1977) considered to regulate *Wiseana* spp. below damage thresholds. Fleming *et al.* (1982) monitored NPV, granulosis virus and entomopox virus, which together caused 90% decrease in larval populations in old pasture and maintained *Wiseana* spp. at low population levels. The fungus *Metarhizium anisopliae* (Metschnikoff) Sorokin infests *W. cervinata* naturally at low levels, and has given control when experimentally applied in baits (Latch & Kain 1983).

Overseas searches for *Wiseana* spp. natural enemies were carried out by CIBC from 1966 to 1970 in conjunction with the Melolonthinae programme in western Argentina (Chapter 2). Lloyd & Blackman (1966) observed populations of hepialid larvae in tussock grass improved with clover and ryegrass, and noted the presence of Carabidae and Tachinidae. The only parasitoids reared were dexiine Tachinidae from the genus *Notodytes* (Lloyd *et al.* 1967). These were identified as *N. variabilis* Aldrich which was reared from *Dalaca pallens* (Blanchard) and *Dalaca variabilis* Viette, and *N. aurea* Aldrich which may have been specific to *D. variabilis*. Lloyd *et al.* (1967) described the biology of these species, which typically larviposit in pasture, the young larvae entering host larvae in the soil. The more common *N. variabilis* had two generations per year and their larvae were capable of attacking early or late instar hosts. This feature is likely to have increased the chances of this species adapting to new hosts. Adult *N. variabilis* were most common at aphid honey dew on willows, and were not seen on flower heads. Parasitism was very variable but occurred at low levels in open pasture habitats. It occasionally exceeded 15% in areas where trees and shrubs were abundant. Experimental inoculations of *Wiseana* spp. with *Notodytes* spp. shipped to Trinidad were unsuccessful (Lloyd *et al.* 1967). Shipments to New Zealand for *Wiseana* spp. control commenced in 1967.

Carabidae, particularly *Pterostichus* (= *Trirammatus*) *unistriatus* (Dejean), occurred in hepialid populations and were active against larvae in laboratory tests (Lloyd *et al.* 1967). This species was consigned to New Zealand with two other predators for release against *Costelytra zealandica* (White).

Importations, Releases and Recoveries

All importations were carried out between 1967 and 1969 (DSIR files). Lloyd *et al.* (1967) reported the shipment of eight female *Notodytes variabilis* and numerous first instar larvae to New Zealand in 1967. The larvae were used for inoculation of *Wiseana* spp., with no success. Shipments of adults in 1968 suffered very high mortality. Ten shipments totalling 175 adult *N. variabilis* produced only 18 live adults. However, live larvae were recovered from both live and dead flies and used for inoculation tests on *Wiseana* spp. No parasitoid development was recorded (DSIR files). Four *N. aurea* shipped in the same year arrived dead. Survival was improved in 1969 shipments by increasing the humidity and water supply. This enabled survival of 121 females from 269 consigned in 12 shipments (Lloyd & Rechencq 1969). No successful development was obtained from 686 inoculations of *Wiseana* spp. (DSIR files) and no material was released into the field.

The importation of the carabid *Pterostichus unistriatus* and release of 587 individuals in the Nelson area is further detailed in Chapter 2 on *C. zealandica*. There were no recoveries.

Evaluation

Experimental inoculation of first instar *N. variabilis* larvae onto *Wiseana* spp. failed to demonstrate development of this parasitoid. Tests carried out in Trinidad are described by

Lloyd *et al.* (1967) as inconclusive, but together with the New Zealand results (DSIR files) they indicate the physiological incompatibility of this parasitoid with *Wiseana* spp.

No exotic species of nematodes have been released against *Wiseana* spp. in New Zealand, but in laboratory tests Jackson *et al.* (1981) showed that larvae were moderately susceptible to *Steinernema glaseri* Steiner and *Heterorhabditis heliothidis* (Khan, Brooks & Hirschmann) Poinar, Thomas & Hess, both imported as strains from Tasmania. The effective field use of the indigenous species *Steinernema bibionis* has been restricted to short periods where adequate soil moisture and warm temperatures coincide with the susceptible young larval stages. The identification of a cool-active strain (Wright & Jackson 1988) indicates the potential to extend this period of infectivity. The effectiveness of *Metarhizium anisopliae* is also restricted by an optimum temperature requirement above those normally experienced in the field.

The use of viruses has been largely centred on the management of pastures to conserve disease populations, as discussed by Wigley (1985). The need to retain virus inoculum in the soil requires non-chemical management practices such as those recommended by Kalmakoff & Crawford (1976) and East & Pottinger (1982).

Conclusions

There appear to be few prospects for the introduction of exotic insect parasitoids or predators for *Wiseana* spp. control, but there may be potential for selecting suitably active strains of nematodes or fungi for importation. There are no specific recommendations in the literature for introducing pathogens, however Wigley (1985) has discussed screening programmes and suggested that screening should include a wide array of endemic and exotic pathogens. Continuing trials with the inundative application of native nematodes and pathogens has demonstrated the potential effectiveness of these organisms. To gain more acceptance these agents need to tolerate a wider range of environmental conditions. In a period when economic conditions dictate minimal input into pasture, the most persistent organisms, as used in inoculative biological control, will have a cost advantage over treatments requiring repeated inundative application.

Literature Cited

Chapman, R.B. (1984) Pasture pests. Pp. 119-142 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury.

Crawford, A.; Kalmakoff, J. (1977) A host-virus interaction in a pasture habitat. *Wiseana* spp. (Lepidoptera: Hepialidae) and its baculoviruses. *Journal of invertebrate pathology* 29, 81-87.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1945) Contribution to the ecology of *Oxycanus cervinata* Walk. *New Zealand journal of science and technology* A 27, 114-128.

East, R.; Pottinger, R.P. (1982) Integrated pasture pest management in New Zealand. Pp. 102-113 in Cameron, P.J.; Wearing, C.H.; Kain, W.M. (eds), Proceedings of the Australasian Workshop on Development and Implementation of IPM. Government Printer, Auckland.

East, R.; Pottinger, R.P. (1984) The cost of pasture pests. *New Zealand agricultural science* 18, 136-140.

Eyles, A.C. (1965) Observations on some parasites of two *Wiseana* species (Lep.: Hepialidae). *New Zealand journal of agricultural research* 8, 951-958.

Eyles. A.C. (1966) A predator on *Wiseana* (Lep.: Hepialidae). *New Zealand journal of agricultural research* 9, 699-703.

Fleming, S.; Archibald, R.; Stewart, K.; Kalmakoff, J. (1982) Natural regulation of *Wiseana* spp. by enzootic disease. Pp. 283-289 in Lee, K.E. (ed.), *Proceedings of the 3rd Australasian Conference on Grassland Invertebrate Ecology*, South Australian Government Printer, Adelaide.

Gourlay, E.S. (1930) Preliminary host list of the entomophagous insects in New Zealand. *New Zealand DSIR bulletin* 22, 1-13.

Jackson, T.A.; Bedding, R.A.; Trought, T.E.T; Kain, W.M.; East, R. (1981) The potential use of nematodes for the control of pasture pests. *Proceedings of the 34th New Zealand Weed and Pest Control Conference*, 170-172.

Kain, W.M.; Wyeth, T.K.; Kale, A.J. (1981) Preliminary field studies on the use of an indigenous parasitic nematode for control of Porina. *Proceedings of the 34th New Zealand Weed and Pest Control Conference*, 173-175.

Kalmakoff, J.; Crawford, A.M. (1976) Virus control of Porina. *New Zealand journal of agriculture* 133, 41-43.

Latch, G.C.M.; Kain, W.M. (1983) Control of Porina caterpillar (*Wiseana* spp.) in pasture by the fungus *Metarhizium anisopliae*. *New Zealand journal of experimental agriculture* 11, 351-354.

Lloyd, D.C.; Blackman, R.L. (1966) Investigations on natural enemies of Melolonthinae and Hepialidae. CIBC unpublished report, 20 pp.

Lloyd, D.C.; Rechencq, F. (1969) Investigations of natural enemies of Melolonthinae and Hepialidae in Argentina. CIBC unpublished report, 20 pp.

Lloyd, D.C.; Blackman, R.L.; Henderson, I.F. (1967) Investigations of natural enemies of Melolonthinae and Hepialidae in South America. CIBC unpublished report, 35 pp.

Perrott, D.C.F. (1974) Porina moth, *Wiseana* spp., life cycle. *DSIR information series* 105/1.

Savage, M.J.; French, R.A. (1981) Porina chemical control. *Aglink* FPP 588. Ministry of Agriculture and Fisheries, Wellington.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

van der Mespel, G.J.; Kain, W.M.; Wouts, W.M. (1986) Evaluation of an entomophagous nematode (*Steinernema bibionis*) for the control of Porina larvae (*Wiseana* spp.) in the Otaki district. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 114-116.

Wigley, P.J. (1985) An evaluation of strategies for using insect pathogens to control pasture pests in New Zealand. Pp. 276-285 in Chapman, R.B. (ed.), *Proceedings of the 4th Australasian Conference on Grassland Invertebrate Ecology*, Caxton Press, Christchurch.

Wright, P.J.; Jackson, T.A. (1988) Low temperature activity and infectivity of a parasitic nematode against Porina and grass grub. *Proceeding of the 41st New Zealand Weed and Pest Control Conference*, 138-140.

PART 2.

Field Crop and Vegetable Pests

The crops referred to in this section range from cereals or brassicas grown in large areas as monocultures, to home garden vegetables. Some of the plant species involved, such as brassicas or maize, can be grown extensively as forage for animals, or intensively as vegetables for human consumption. In extensively grown crops insecticide use tends to be low, while in high value vegetable crops where damage tolerance levels are low, produce quality can demand high levels of insecticide use. The target pests in this section therefore occur over a wide range of habitats and varying management environments. Their natural enemies, and the role they play in control of the pests covered here, also vary greatly between crops.

Field crops in this review are defined to include cereals, forage brassicas, peas for drying and clover seed crops. Basic statistics on crop production and utilization in New Zealand are provided by Logan (1983). The major cereal crops in New Zealand are barley, oats, maize and wheat. Apart from barley, these cereals are grown mostly for domestic consumption. Forage brassicas are an important part of pastoral farming and include kale, rape, turnips and swede. Large areas of peas are grown for export in dried form, but these are mainly in South Island areas where insect pests are not a serious problem. White clover seed is also a significant export. Cosmopolitan aphid and lepidopteran species have been the main targets for biological control in these crops. By comparison with most major world field cropping areas, pulse and oilseed crops are uncommon in New Zealand.

By crop area, potatoes are the major vegetable and are grown mostly for the domestic market. Peas harvested for freezing or canning occupy a similar land area and are largely exported. The other main export earners amongst the vegetable crops are onions and squash, but neither of these crops are major hosts for pests which have been targets for biological control. Other crops occupy relatively small land areas but are very important in the domestic market. Natural enemies have been imported for inoculative release against pests of beans, brassicas, potatoes, sweet corn and tomatoes, as well as some generalist pests which attack a wide range of crops.

The pest complement of field crops and vegetables is often not as broad as in other temperate regions, but new pest species are still arriving in New Zealand. Many of the accidentally introduced pests have been shown to be relatively free of natural enemies and have rapidly developed damaging populations in New Zealand. Classical biological control through the introduction of natural enemies has therefore been a logical control strategy. Many of the agents have been obtained through CIBC stations, with the greatest activity occurring in the 1960s (55 importation records) when the majority of the aphid predators and *Phthorimaea operculella* (Zeller) parasitoids were imported from Pakistan and India. The other major sources have been Europe (35 records) and North America (22 records).

Biological control of cereal pests includes the first introduction into New Zealand of parasitoids, in 1894, for control of *Mayetiola destructor* (Say) (Chapter 17). The impact of these introduced parasitoids has not been fully evaluated. Other biological control attempts in cereals have been directed against aphids, through the use of general predators (Chapter 11) and specific parasitoids (Chapter 18). *Coccinella undecimpunctata* L., considered to be the first natural enemy released into New Zealand in 1874, has an unpredictable impact on some aphid populations but predators introduced more recently have failed to become established. Recent introductions of parasitoids for *Metopolophium dirhodum* (Walker) have been more successful (Chapter 18).

Significant introductions were made by B.B. Given and J. Muggeridge against the brassica pests *Pieris rapae* and *Plutella xylostella* (L.) in the 1930s. These included the first exports of *P. xylostella* parasitoids from Europe to any other part of the world for biological control. *Diadegma semiclausum* Hellén and *Diadromus collaris* (Gravenhorst) are considered to contribute to adequate control of *P. xylostella* in forage crops in New Zealand, and have been shipped to several other countries (Chapter 24). Introduced parasitoids have also reduced the damage caused by *Pieris rapae* (Chapter 23).

Several programmes were initiated by R.A. Cumber against noctuid pests from 1969 to 1975. The most successful of these was the introduction of *Apanteles ruficrus* (Haliday) for control of *Mythimna separata* (Walker). Following the establishment of *A. ruficrus*, chemical control of this pest in graminaceous crops is rarely necessary (Chapter 19). This is considered to be one of the outstanding examples of biological control in recent years. Partial success has recently been achieved with the introduction of parasitoids of *Helicoverpa armigera* (Hübner) (Chapter 14).

The use of biological control against Coleophoridae in clover is unique to New Zealand and reflects the importance of clovers in this country. The large number of species imported by A.M. Stuart and W.P. Thomas during this programme resulted in the establishment of two parasitoids which have contributed significantly to control of these pests (Chapter 13).

The largest number of introductions for a vegetable or field crop pest is recorded against *Phthorimaea operculella* (Zeller). The release of 67 species resulted in the establishment of one parasitoid but this is considered to have little economic impact on this pest (Chapter 22).

In summary, 103 species have been imported against 17 field crop and vegetable pests. This is the largest number of agents introduced against any group of pests (see General Introduction), and reflects the cosmopolitan nature of these pests and therefore the availability of agents. Of the 79 release records, 15 resulted in establishment of new species, whereas six agents were recovered but did not establish permanently. This relatively low establishment rate results from a strategy of multiple introductions for some pests. Agents were sometimes imported as parasitised hosts and relatively few individuals of many species were released over a short period. Although these small releases may have limited the chances of establishment of particular agents, multiple introductions may have increased the number of targets against which an establishment has been obtained. An analysis shows that at least one natural enemy has been established against 11 of 17 targets. Impacts of varying degrees have been reported against populations of eight target pests; *Coleophora* spp., *Helicoverpa armigera*, *Metopolophium dirhodum*, *Mythimna separata*, *Nezara viridula* (L.), *Phthorimaea operculella*, *Pieris rapae* and *Plutella xylostella*. These are reported in detail in the chapters on each target pest.

The reduced rate of importations over the past decade indicates a trend towards single or limited introductions of species for biological control, and the need to evaluate those agents already established. There appear to be greater prospects for biological control of pests in processing crops, where some damage can be tolerated, and the benefits of biological control can be observed by the reduced need to spray. In maize, growers often recognise that *A. ruficrus* contributes to control of *M. separata*. Currently there are also attempts to develop integrated control strategies for *H. armigera*. However, pest control in most intensive vegetable cropping relies on routine spraying schedules and the benefits of biological control are limited to the impact on pests in unsprayed areas. As the risks of insecticide resistance and chemical residues increase, and selective insecticides are more commonly used, biological control is gaining greater recognition as an important component for control of field crop and vegetable pests.

Literature Cited

Logan, L.A. (1983) Crop production and utilisation in New Zealand. Crop Research Division DSIR, report no. 81, 210 pp.

Agromyzidae, leaf miners (Diptera)

P.G. McGREGOR

Pest Status

Pest species of Agromyzidae are widely distributed throughout the world and infest many important crops. Damage is caused primarily by larvae, which are mainly leaf miners, but some are stem borers or gall makers (Hill 1987, Parella 1987, Spencer 1973, Talekar & Chen 1985).

New Zealand has 41 described species of Agromyzidae in the genera *Cerodontha*, *Hexomyza*, *Liriomyza*, *Melanagromyza*, *Phytoliriomyza* and *Phytomyza* (Spencer 1976). Some species present in New Zealand are serious pests overseas (Spencer 1973) but their pest status in New Zealand is uncertain. The cosmopolitan pest *Liriomyza brassicae* (Riley) is not recorded as a significant pest in New Zealand. *Liriomyza chenopodii* (Watt) may damage beet and spinach (Butcher 1984, Pearson & Goldson 1980, Spencer 1976, Wise 1953). *Liriomyza clianthi* (Watt) can severely damage the ornamental kaka beak (*Clianthus puniceus* (Don) Banks & Selander (Somerfield 1984, Wise 1953). *Chromatomyia syngenesiae* Hardy was probably accidentally introduced from Britain (Spencer 1976). It is mainly a pest in glasshouses, where it damages Asteraceae, especially chrysanthemums (Somerfield 1984). *Chromatomyia syngenesiae* has been regarded as not important in cultivated crops in New Zealand (E.W. Valentine in DSIR files). Like the endemic *Melanagromyza senecionella* Spencer, it also infests the weed ragwort (*Senecio jacobaea* L.) (Asteraceae) and has been considered to have limited potential as a biological control agent for this weed (Kelsey 1937, Spencer 1976). *Cerodontha australis* Malloch was misidentified in New Zealand as *C. denticornis* (Meigen in Panzer) until Spencer's (1976) review. Despite its frequent incidence in many grasses, including cereals, it apparently does not cause significant damage (Barker *et al.* 1984, Burnett 1984).

Agromyzid leaf miners typically lay eggs on or in leaves. Larvae tunnel in leaves, creating characteristic mines that often assist identification of the leaf miner species. Pupation may occur inside the leaf or larvae may leave the plant to pupate. Kelsey (1937) showed that *C. syngenesiae* could complete 15 generations per year in New Zealand.

Background

Two species of Hymenoptera had been recorded as parasitising *Chromatomyia syngenesiae* before introductions for biological control began. These were *Chrysocharis* sp. (Eulophidae) (Valentine 1967), probably *C. pubicornis* (Zetterstedt) (DSIR files), and *Dacnusa areolaris* Nees (Braconidae) (Kelsey 1937). Watt (1923) recorded 90% parasitism of *Chromatomyia syngenesiae* larvae but did not identify the species and Kelsey (1937) claimed that 40-65% parasitism of *C. syngenesiae* was normal. This parasitoid was presumably *D. areolaris*. *Hemiptarsenus* sp. (Eulophidae) had also been recorded from *L. chenopodii* and *Cerodontha australis* (Valentine 1967). This was probably *Hemiptarsenus semialbiclavus* (Girault) (Valentine & Walker 1989). Cumber & Eyles (1961a) recorded *Hemiptarsenus* sp. associated with various crops including brassicas. *Diglyphus isaea* (Walker) (Eulophidae) apparently established in New Zealand on *C. syngenesiae* before its introduction for leaf miner control (Valentine & Walker 1989).

In the late 1960s reports of apparent agromyzid leaf miner damage to brassicas were relayed to Entomology Division, DSIR. In 1968, Entomology Division agreed to ask the CIBC for information on possible biological control of what was called 'brassica leaf miner'. This was assumed to be *C. syngenesiae*, known then as *Phytomyza atricornis* auct. (DSIR files). Initial approaches through CIBC to the Glasshouse Crops Research Institute (GCRI), U.K., led to the offer from GCRI of *C. syngenesiae* parasitoids for rearing in New Zealand. This was not acceptable, largely because of lack of resources for mass rearing in New Zealand. CIBC then offered to accept the parasitoids from GCRI and rear them in Pakistan for shipment to, and direct release in, New Zealand. Before the U.K. material arrived, CIBC in Pakistan reared parasitoids from locally-collected hosts. The host agromyzids from which all parasitoids for New Zealand were obtained were eventually determined as *Chromatomyia horticola* (Goureau) and *Liriomyza brassicae* (DSIR files).

During the course of the programme it was discovered that the damaging leaf miners were not Agromyzidae, but two species of Drosophilidae: *Scaptomyza graminum* (Fallén) and *Scaptomyza* (*Parascaptomyza*) *elmoi* Takada (known then as *Scaptomyza flava* (Fallén) (DSIR files)). CIBC began a survey of parasitoids of *Scaptomyza* spp. in Pakistan in March 1971 but found none (Anwar 1972). The project apparently ended in 1971 (DSIR files).

Importations, Releases and Recoveries

The first shipment of leaf miner parasitoids arrived in New Zealand in October 1969. This comprised 734 adults of *Diglyphus* sp., 38 adults of *Opius* sp. (Braconidae) (misidentified as *Rhizarcha* sp.) and 47 adults of a eulophid questionably identified as *Chrysocharis* sp. Some secondary parasitoids (Pteromalidae) were also included. No suitable leaf miner infestations were available then. The putative *Chrysocharis* sp. was not released. *Opius* sp. may also not have been released. About 250 *Diglyphus* sp. were apparently released in Nelson (DSIR files).

Between 12 November 1969 and 9 January 1970 a further nine consignments totalling 100 *Diglyphus* spp. adults and 2,210 larvae of *Chromatomyia horticola* and *L. brassicae* parasitised by *Diglyphus* spp. arrived in New Zealand. Records from six of these shipments suggest that adult *Diglyphus* spp. emerged from 10-45% of the larvae. Most of these were released near Nelson. 350 *Diglyphus* sp. adults were released in chou moellier (*Brassica oleracea* var. *ramosa*) crops near Hamilton. Leaf miner incidence there was low, but regarded as 'sufficient for establishment' of the parasitoids (DSIR files). All subsequent consignments of parasitoids to New Zealand were of adults.

Twenty more consignments of parasitoids were sent to New Zealand, arriving between 25 February 1970 and 13 April 1971. Sixteen of these included *Diglyphus* spp. During this period 11,821 adult *Diglyphus* spp. were sent and more than 11,000 survived to be released; 9,113 were released near Ashburton in South Canterbury; 768 were released at Lincoln near Christchurch (DSIR files). There are no records concerning the remainder.

The species of *Diglyphus* sent to New Zealand were later identified as *Diglyphus minoeus* (Walker), *D. isaea* (Walker) and *Diglyphus* sp. nr. *chabrias* (Walker) (Anwar & Ghani 1970, Valentine & Walker 1989).

There are no records of recoveries of *D. minoeus* and the unidentified *Diglyphus* sp. *D. isaea* had apparently already established in New Zealand before its introduction for leaf miner control (Valentine & Walker 1989).

Thirteen shipments of *Tetrastichus* sp. were sent to New Zealand. Between April and October 1970, 1,663 adults were sent in consecutive consignments from Pakistan. All 228 adults in the last two shipments died in transit. Two further consignments totalling 152 adults were received during April 1971, but the 100 *Tetrastichus* sp. in the second shipment died

in transit. At least 957 *Tetrastichus* sp. adults were released at several sites in South Canterbury and at least 430 were released at Lincoln. The species was never recovered (DSIR files).

Some confusion surrounds the *Chrysocharis* sp. sent to New Zealand. The first consignment of parasitoids to New Zealand included 47 adult Eulophidae that were tentatively determined as *Chrysocharis* sp. These were not released. Three consignments in April 1970 included 204 adult *Chrysocharis* sp. reared in Pakistan from *Chromatomyia horticola*. These were released onto brassicas near Ashburton. On 7 and 28 November 1970 two consignments including 218 adult parasitoids tentatively identified as *Chrysocharis* sp. were sent from Pakistan. These had been reared in Pakistan from *L. brassicae*. By 16 January 1971 the species from these two consignments had been determined as *Hemiptarsenus semialbiclavus* (Girault). Three further shipments contained 553 adult *H. semialbiclavus*. In total between December 1970 and March 1971, 653 *H. semialbiclavus* were released at Lincoln on brassicas and *Sonchus* sp. and 100 at Ashburton on turnips. The last two consignments of parasitoids to New Zealand, on 3 and 10 April 1971, contained 280 adult *Chrysocharis* sp., reared from *Chromatomyia horticola*. One hundred and thirty of these were released onto turnips, rape (*Brassica napus* var. *oleifera*) and grasses at Ashburton (DSIR files). The remainder may not have been released. There is little doubt that these were *Chrysocharis* sp. and not misidentified *H. semialbiclavus*.

Table 9.1 Importations and releases of parasitoids for control of brassica leaf miners in New Zealand. Only definite records of releases have been included in totals.

Species	Stages imported	Period imported	Number of shipments	Number definitely released
Chrysocharis sp.	Adults	28 Oct. 1969-13 Apr. 1971	6	177
Diglyphus spp.	Host larvae	12 Nov. 1969-9 Feb. 1970	8	364
	Adults	28 Oct. 1969-13 Apr. 1971	19	10,131
Hemiptarsenus semialbiclavus	Adults	10 Nov. 1970	5	753
Opius sp.	Adults	28 Oct. 1969-1 Dec. 1970	6	98
Tetrastichus sp.	Adults	2 Apr. 1970-13 Apr. 1971	13	1,387

Chrysocharis pubicornis and *Hemiptarsenus semialbiclavus* were both probably already present in New Zealand parasitising Agromyzidae before the leaf miner control programme began. No other species in these genera have been recorded from Agromyzidae in New Zealand (Valentine & Walker 1989).

Importations and releases of parasitoids for leafminer control in New Zealand are summarised in Table 9.1.

Evaluation

No new parasitoids of Agromyzidae became established during the programme, although this conclusion assumes that Valentine & Walker (1989) correctly speculated that *D. isaea* was already present.

The failure was probably due to misidentification of the target. The initial assumption that the 'brassica leaf miner' was *Chromatomyia syngenesiae* proved wrong. This mistake would not have affected the programme if the main leaf miners of brassicas in New Zealand had been *C. horticola* and *L. brassicae* because parasitoids were obtained from these species in Pakistan. However, of these agromyzids, *C. horticola* does not occur in New Zealand and *L. brassicae* is apparently unimportant.

It is very unlikely that the parasitoids of Agromyzidae would have parasitised the *Scaptomyza* spp. that appear to have been the main leaf-mining pests. In Pakistan, *Scaptomyza* sp. (possibly *S. elmoi*) infested crops that were also infested with *Chromatomyia horticola* and *Liriomyza brassicae*. The agromyzids were parasitised by *Diglyphus* sp., *Tetrastichus* sp. and *Opius phaseoli* Fischer, but *Scaptomyza* sp. was not parasitised (Anwar 1972).

Conclusions

Leaf-mining Agromyzidae do not appear to be as economically important in New Zealand as they are overseas. This may be because the most serious pests such as *Liriomyza trifolii* (Burgess) (Parella 1987) are not present, or because economic injury levels are so difficult to assess (Minkenberg & van Lenteren 1986). Parasitoids already present in New Zealand may restrict populations of potentially damaging agromyzid leaf miners. Further biological control attempts for Agromyzidae are not warranted now. The arrival of major pests such as *L. trifolii* could alter this conclusion. Most other forms of control of leaf miners are only partially effective and some can make the problem worse by killing leaf miner parasitoids (Minkenberg & van Lenteren 1986).

The role of *Scaptomyza* spp. as leaf-mining pests of brassicas in New Zealand is not understood as no pest assessment studies of *Scaptomyza* spp. have been carried out here. There are no published records of damage attributed to *Scaptomyza* spp. in New Zealand, although Cumber & Eyles (1961b) associated *S. fuscitarsus* Harrison with various crops. The New Zealand Arthropod Collection contains *S. elmoi* reared from various brassicas, *Tropaeolum majus* L. and *Pisum sativum* L. (B.A. Holloway pers. comm.). The genus contains known pests of brassicas elsewhere (Carillo & Palma 1982, Hill 1987, John *et al.* 1984, Taylor 1984).

First priority for research on leaf miners on brassicas in New Zealand must be identification of the insects and the extent of their damage. No biological control programme can be expected to succeed without this information. However, until significant damage is reported there will be little incentive to proceed with this research.

Acknowledgements

I thank P.J. Cameron for a great deal of help in locating much of the DSIR information and B.A. Holloway for information on *S. elmoi*.

Literature Cited

Anwar, A.M. (1972) Project 8. Parasites of *Scaptomyza* (for New Zealand). Commonwealth Institute of Biological Control, Report of work carried out in 1972, 60.

Anwar, A.M.; Ghani, M.A. (1970) Project 15. Parasites of *Phytomyza* (for New Zealand). Commonwealth Institute of Biological Control, Report of work carried out in 1970, 75.

Barker, G.M.; Pottinger, R.P.; Addison, P.J.; Oliver, E.H.A. (1984) Pest status of *Cerodontha* spp. and other shoot flies in Waikato pastures. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 96-100.

Burnett, P.A. (1984) Cereal crop pests. Pp. 153-167 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Butcher, M.R. (1984) Vegetable crop pests. Pp. 93-118 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Carillo, L., R.; Palma G., J.C. (1982) Descripcion morfologica de los estados preimaginales de *Scaptomyza multispinosa* Malloch (Diptera – Drosophilidae). *Boletin de la sociedad de biologia de Concepcion* 53, 25-31.

Cumber, R.A.; Eyles, A.C. (1961a) Insects associated with the major fodder crops in the North Island. IV. Hymenoptera. *New Zealand journal of agricultural research* 4, 390-408.

Cumber, R.A.; Eyles, A.C. (1961b) Insects associated with the major fodder crops in the North Island. V. Diptera. *New Zealand journal of agricultural research* 4, 409-425.

DSIR, Entomology Division, file BC 1/4.

Hill, D.S. (1987) Agricultural insect pests of temperate regions and their control. Cambridge University Press, Cambridge. 659 pp.

John, M.E.; Vaughan, J.; Evans, E.J. (1984) Control of pests and diseases of oilseed rape. Booklet, Ministry of Agriculture, Fisheries and Food, U.K., no. 2387. 55 pp.

Kelsey, J.M. (1937) The ragwort leaf-miner (*Phytomyza atricornis* Mg.) and its parasite (*Dacnusa areolaris* Nees.). *New Zealand journal of science and technology (A)* 18, 762-767.

Minkenberg, O.P.J.M.; van Lenteren, J.C. (1986) The leafminers *Liriomyza bryoniae* and *L. trifolii* (Diptera: Agromyzidae), their parasites and host plants: a review. Agricultural University Wageningen papers 86-2. Agricultural University Wageningen, Netherlands. 50 pp.

Parella, M.P. (1987) Biology of *Liriomyza*. *Annual review of entomology* 32, 201-224.

Pearson, J.F.; Goldson, S.L. (1980) A preliminary examination of pests in fodder beet in Canterbury. *Proceedings of the 28th New Zealand Weed and Pest Control Conference*, 193-195.

Somerfield, K.G. (1984) Greenhouse and ornamental pests. Pp. 65-92 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Spencer, K.A. (1973) Agromyzidae (Diptera) of economic importance. Dr. W. Junk, The Hague. 418 pp.

Spencer, K.A. (1976) The Agromyzidae of New Zealand (Insecta: Diptera). *Journal of the Royal Society of New Zealand* 6, 153-211.

Talekar, N.S.; Chen, B.S. (1985) The beanfly pest complex of tropical soybean. Pp. 257-271 in Shanmugasundaram, S.; Sulzberger, E.W. (eds), Soybean in tropical and subtropical cropping systems. Proceedings of a symposium, Tsukuba, Japan, 26 September – 1 October 1983. Asian Vegetable Research and Development Centre, Shanhua, Taiwan.

Taylor, B. (1984) Chinese cabbage. Booklet, Ministry of Agriculture, Fisheries and Food, U.K., no. 2336. 33 pp.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Valentine, E.W.; Walker, A.K. (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, (in press).

Watt, M. (1923) The leaf-mining insects of New Zealand: Part III – Species belonging to the Genera *Agromyza* (Fallén) and *Phytomyza* (Fallén) (Diptera). *Transactions and Proceedings of the New Zealand Institute* 54, 465-489.

Wise, K.J. (1953) Leaf-mining pests in New Zealand. *New Zealand journal of agriculture* 87, 75-76.

Agrotis ipsilon (Hufnagel), greasy cutworm (Lepidoptera: Noctuidae)

D.J. ALLAN

Pest Status

The Pacific subspecies of the black cutworm is the greasy cutworm *Agrotis ipsilon aneituma* (Walker) and is found in New Zealand, Australia, New Guinea and islands of the South Pacific. In New Zealand there is evidence to suggest that local populations are frequently supplemented by migrants from Australia (Fox 1976).

Pastures often support many *A. ipsilon* larvae, but the damage is not usually noticeable. Where infested land is adjacent to crops, or is converted to cropping, the spread or carry-over of *A. ipsilon* can cause substantial crop loss. A wide variety of plants are damaged, particularly at the seedling stage. Graminaceous crops such as corn, wheat and barley are most commonly affected but almost any seedling crop may be damaged. Greasy cutworm is recorded as probably the most common and persistent insect pest attacking maize and sweetcorn (Watson & Martin 1981).

Eggs are laid singly or in small clusters, randomly placed on vegetation or open ground, and hatch in three to seven days. The larval stage takes about four to six weeks and pupae take two to three weeks to develop. The normal summer life cycle lasts between seven and ten weeks and there are two to three generations per year depending on the locality (Allan 1975).

Weedy seed beds encourage early infestation and so predispose the crop to damaging populations while the plants are small and vulnerable. Young larvae feed on foliage, but the characteristic habit of larger larvae cutting through the bases of small plants gives them the common name of cutworms and causes damage out of proportion to their numbers.

Background

Outbreaks of cutworms in New Zealand are typically sporadic from season to season and place to place. The factors governing outbreaks are essentially unknown. Influxes of migratory moths from Australia may contribute to the unstable, sporadic nature of these outbreaks. There is a background level of natural control but only occasionally is this sufficient to provide economic control.

The native braconid *Macrocentrus rubromaculatus* (Cameron) is occasionally reared from large larvae and pre-pupae of *A. ipsilon* collected late in the summer (Hill *et al.* 1985). The unknown ichneumonid reported in Hill *et al.* (1985) has since been successfully reared from pre-pupae and identified as *Enicospilis insularis* (Kirby). This is the first host record for this species in New Zealand. Parasitism has been found to be between 0.5 and 1.0% of larvae collected in the Auckland district (Allan unpublished data).

Two tachinids, *Plagiomyia longicornis* Malloch and *Pales efferata* (Hutton), occur in some populations of *A. ipsilon* and may occasionally parasitise up to 30% of the larvae (Hill *et al.* 1985, Valentine 1967).

The pentatomid *Cermatulus nasalis* (Westwood) has been recorded as feeding on *A. ipsilon* larvae (Valentine 1967).

Vavraia (= *Pleistophora*) *oncoperae* (Milner & Beaton), a microsporidian disease, is the only pathogen that has been isolated from diseased cultures of *A. ipsilon* in Auckland (Malone *et al.* 1987). Field collections in 1975 suffered 26% mortality from unknown causes

(Hill *et al.* 1985) which may have included microsporidia. The cause of mortality was not determined but recognition of microsporidia is now possible through improved techniques (Wigley *et al.* 1986).

Importations, Releases and Recoveries

1969-72

In the late 1960s a programme was initiated to introduce *A. ipsilon* parasitoids into New Zealand. *Apanteles* (= *Cotesia*) *ruficrus* (Haliday) (Braconidae) was liberated in 1970-72, and while it established readily and was recovered from *Mythimna separata* (Walker) (Noctuidae), it was not until a 1975-76 survey that the species was recovered from *Agrotis ipsilon* (Hill *et al.* 1985). Further discussion on *Apanteles ruficrus* is found in Chapter 19 on *M. separata*. *Macrocentrus collaris* (Spinola) (Braconidae) was received from Pakistan in 1971 and reared and released in large numbers (Cumber *et al.* 1977). Several surveys since then have recovered the native *M. rubromaculatus* but have failed to recover *M. collaris* (Hill *et al.* 1985). Seven other species were imported but not released. All imported species are shown in Table 10.1.

Table 10.1 Parasitoids imported into New Zealand for the control of *Agrotis ipsilon*.

Species	Imported	Status
	Pakistan	
HYMENOPTERA: BRACONIDAE		
Apanteles ruficrus (Haliday)	1970-71	Released 1970, estab. 1970
Apanteles sp.	1969	Not released
Macrocentrus collaris Spinola	1971	Released 1971-72, not recovered
ICHNEUMONIDAE		
Ctenichneumon panzeri	1969	Not released
(Wesmael)	1985-86	Not released
DIPTERA: TACHINIDAE		
Periscepsia carbonaria Panzer	1970-71	Not released
	1985-86	Not released
Species A	1969	Not released
Species B	1969	Not released
Species C	1969	Not released
Turanogonia chinensis Wiedemann (= *T. smirnovi* Rohdendorf)	1969-71	Not released
	U.S.A.	
Linnaemyia comta (Fallén)	1981-82	Released 1982, not recovered

1981-82

Linnaemyia (= *Bonnetia*) *comta* (Fallén) (Tachinidae) was imported from the U.S.A. in 1981-82 and released in the Auckland, Pukekohe, Gisborne and Tolaga Bay maize growing areas (Allan & Hill 1984). *L. comta* is one of the more effective parasitoids of *Agrotis* spp. in the U.S.A. where it parasitises up to 27% of black cutworms in Ohio (Levine & Clement 1981) and in China where up to 50% of field cutworms are parasitised (Wen *et al.* 1965). This species is also found in Europe.

A total of 7,650 mated female flies and 2,200 parasitised larvae was released. A field assessment programme in all release areas failed to recover any *L. comta* (Allan & Hill 1984).

1985-86

Re-importations from Pakistan were made of two species which were unable to be released following imports in the 1969-72 period. These were *Ctenichneumon panzeri* (Wesmael) (Ichneumonidae) and *Periscepsia carbonaria* (Panzer) (Tachinidae). These two species were chosen mainly because they parasitise larval sizes complementary to those parasitised by the existing *Apanteles ruficrus*. A sex ratio imbalance resulting from poor emergence out of the 1985 shipments eventually caused the laboratory cultures to fail after two generations. As field infestations in Pakistan were low in 1986, no shipments were sent.

Evaluation

In the early summer *Apanteles ruficrus* consistently parasitises 5-10% of *Agrotis ipsilon*. The host range of *Apanteles ruficrus* in the field includes *Mythimna separata* and to a lesser degree *Chrysodeixis eriosoma* (Doubleday) (Noctuidae). In laboratory rearing, no difficulties were experienced when using both *Agrotis ipsilon* and *M. separata* as host cultures and changing *Apanteles ruficrus* reared on one host onto the other. This ease of switching between host species provides a sequence of hosts for *Apanteles ruficrus* which may explain the consistency of its availability in the field to parasitise both *Agrotis ipsilon* and *M. separata*.

The oligophagous native tachinids *Plagiomyia longicornis* and *Pales efferata* may parasitise up to 30% of *A. ipsilon* but their populations are not predictable. The other cutworm parasitoids may kill up to 2%. The level of mortality caused by the microsporidian disease *Vavraia oncoperae* is unknown.

Conclusions

Overseas no one parasitoid exerts complete control but several species regularly parasitise greater than 20% of *A. ipsilon* through the season. These may also be components of a much more effective parasitoid complex. Puttler & Thewke (1970) record a total complex parasitism rate of 68.8% in Missouri. Of this, 24.1% was parasitism by *Microplitis feltiae* Muesebeck (Braconidae). Exact parasitism rates are sometimes difficult to extract from the literature as parasitism is often recorded for a whole natural enemy complex without a breakdown for individual species. Parasitoids regularly cited as being found in at least 20% of *A. ipsilon* are *L. comta*, *Periscepsia carbonaria*, *Ctenichneumon panzeri* and *M. feltiae*. *Meteorus laeviventris* Wesmael (Braconidae) is another potential candidate for introduction but the only published reports are inadequate to make firm recommendations (El-Minshawy 1970, Schoenbolm & Turpin 1977). Control by pathogens does not seem practical at this stage although new strains of *Bacillus thuringiensis* Berliner are known to show some activity against *A. ipsilon* (Mohd-Salleh *et al.* 1980). The effectiveness of the microsporidian *V. oncoperae* is largely unknown.

While no natural enemies of *A. ipsilon* are being introduced at present it is still regarded as being the most common and persistent pest in corn and maize. At the present level of less than 10% parasitism there is potential for other parasitoids to be effective. Large migratory influxes of moths in some years, either from other parts of New Zealand or Australia, indicate that there may be a continued need for chemical control of the progeny. Higher levels of parasitism could reduce the number of outbreaks requiring chemical control and form the basis of pest management schemes where procedures would be designed to conserve and enhance the parasitoid populations.

Acknowledgements

I wish to acknowledge the co-operative efforts of many colleagues, especially M.G. Hill, E.W. Valentine for the identification of *E. insularis*, and L.A. Malone and Pathology Group, Entomology Division, DSIR for the identification and advice about *V. oncoperae*.

Literature Cited

Allan, D.J. (1975) Greasy cutworm, *Agrotis ipsilon* Hufnagel, life cycle. DSIR information series no. 105/11.

Allan, D.J.; Hill, M.G. (1984) Rearing and release of *Bonnetia comta* (Diptera: Tachinidae), a parasite of *Agrotis ipsilon* (Lepidoptera: Noctuidae). *New Zealand entomologist* 8, 71-74.

Cumber, R.A.; Allan, D.J.; Helmore, L. (1977) Introduction and successful establishment in New Zealand of further strains of *Apanteles ruficrus* Haliday (Hymenoptera: Braconidae) to combat *Pseudaletia* (*Mythimna*) *separata* (Walk.) (Lepidoptera: Noctuidae). *New Zealand journal of agricultural research* 20, 255-258.

El-Minshawy, A.M. (1970) Preliminary notes on the biology of *Meteorus laeviventris* Wesmael an internal parasite of *Agrotis ipsilon* Rott. *Bulletin of the Entomological Society of Egypt* 54, 361-364.

Fox, K.W. (1976) Migrant lepidoptera in New Zealand 1974-75. *New Zealand entomologist* 6, 199-200.

Hill, R.L.; Cumber, R.A.; Allan, D.J. (1985) Parasitoids introduced to attack larvae of the Noctuidae (Lepidoptera) and their establishment in New Zealand 1968-1978. Entomology Division report, 5. 24 pp.

Levine, E.; Clement, S.L. (1981) Effect of parasitism by *Bonnetia comta* on larvae of *Agrotis ipsilon*. *Journal of the Kansas Entomological Society* 54, 219-222.

Malone, L.A.; Wigley, P.J.; Dhana, S.D. (1987) Identity of a microsporidium from three New Zealand pasture insects, *Costelytra zealandica* (Coleoptera, Scarabaeidae), *Wiseana* spp. (Lepidoptera, Hepialidae) and *Listronotus bonariensis* (Coleoptera, Curculionidae). *Journal of invertebrate pathology* 49, 135-144.

Mohd-Salleh, M.B.; Beegle, C.C.; Lewis, L.C. (1980) Fermentation media and production of exotoxin by three varieties of *Bacillus thuringiensis*. *Journal of invertebrate pathology* 35, 75-83.

Puttler, B.; Thewke, S.E. (1970) Biology of *Microplitis feltiae* (Hymenoptera: Braconidae), a parasite of the black cutworm, *Agrotis ipsilon*. *Annals of the Entomological Society of America* 63, 645-648.

Schoenbolm, B.M.; Turpin, F.T. (1977) Parasites reared from black cutworm larvae (*Agrotis ipsilon* Hufnagel) (Lepidoptera: Noctuidae) collected in Indiana corn fields from 1947 to 1977. *Proceedings of the Indiana Academy of Science* 87, 243-244.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Watson, R.N.; Martin, N.A. (1981) Greasy cutworm in maize and sweetcorn; biology, damage and control. *Aglink FPP (Farm production and practice)* 514. New Zealand Ministry of Agriculture and Fisheries, Wellington.

Wen, Y.K.; Ching-Yang; Y. Tseng-Fang (1965) Biological studies on *Linnaemyia compta* Fallén (Diptera: Larvaevoridae). *Acta entomologica Sinica* 14, 159-177.

Wigley, P.J.; Malone, L.A.; Dhana, S. (1986) Screening insect pathogens for pest control. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 126-129.

Aphididae, aphids (Homoptera)

W.P. THOMAS

Pest Status

Aphids are well known for the debilitating feeding effects which they have on plants and for their part in the transmission of virus diseases from plant to plant while feeding. The probing of different plants prior to aphid settlement can also transmit disease (Swensen 1973). They also weaken plants through the insertion of their piercing mouth parts into the phloem or parenchyma leaf tissue of hosts, removal of massive amounts of sap, and at the same time they inject toxins which often distort growth.

Members of the family Aphididae are referred to as aphids, plant 'lice', or 'green fly'. Aphid pests of horticulture and agriculture in New Zealand are all exotic in origin. Cottier (1953) recognised some 53 species of introduced aphids and six endemic species which are relatively rare. By 1972, Lowe (1973) recognised the presence of more than 80 species of exotic aphids in this country and this number has increased since then. The rose-grain aphid (Chapter 18), blue-green lucerne aphid and pea aphid (Chapter 1), and spotted alfalfa aphid (Chapter 7) have all become important pests in New Zealand in recent years. The specific biological and chemical control measures developed for these species, and for the woolly apple aphid (Chapter 34), are not considered here.

Of the large number of exotic aphids present in New Zealand five important field and fruit crop species were initially considered as the targets for biological control in the second phase (from 1965) of introductions of beneficial insects, although it is recognised that many other species which attack various host plants in New Zealand can be of sporadic or of regional importance.

The most comprehensive taxonomic treatise to date on aphids in New Zealand was prepared by Cottier (1953) with notes on their respective biologies. The major species that cause serious damage to cruciferous and cereal crops are:

1. *Brevicoryne brassicae* L. This highly host-specific species was first reported by Travers (1864) on wild turnip and was referred to by Fereday (1872) as 'cabbage blight' which is particularly damaging to cruciferous fodder crops grown in New Zealand. The importance of this species in Canterbury is outlined by Lowe (1973). Their feeding is particularly damaging to the growth of young brassicas, or to the seed yield and oil production in a range of cruciferous crops. Lowe (1967a) showed this to be the most abundant aphid species caught in traps. Winged adults of this species fly onto crops planted in spring where they multiply rapidly from August to November and in Canterbury can increase to 600 per plant (Lowe 1958b). Details of the population dynamics of *B. brassicae* in New Zealand and the key mortality factors have been studied by McLaren (1968, 1975). In New Zealand, various resistant lines of brassicas such as rape, *Brassica napus* variety 'Rangi'(developed by Crop Research Division DSIR) have been bred for resistance to *B. brassicae*.

2. *Myzus persicae* (Sulzer). This species is often abundant and co-exists on brassicas with *B. brassicae*. It is important as an agent of leaf-curl spread in stone (summer) fruit and has been noted by Lange (1987) to be the vector of over 100 viruses.

3. *Rhopalosiphum padi* (L.), *Sitobion miscanthi* (Takahashi) and *Macrosiphum euphorbiae* (Thomas). The presence of barley yellow dwarf virus in New Zealand was demonstrated in wheat by Smith (1963), the main vector being *R. padi*. The life cycles and relationships

between *R. padi* and *S. miscanthi*, their hosts in New Zealand, and the transmission of viruses are described by Burnett (1984). *R. padi* and *S. miscanthi* are widespread in New Zealand on various crops which act as host plants. Grasses are important hosts at certain times of the year. Smith (1963) indicated that aphids could be controlled by a single insecticide spray, increasing yields of wheat by 20% . Because financial returns from agricultural field crops are generally much lower per hectare than many horticultural crops, Lowe (1973) suggested limiting aphicide use to single applications for specific problems. However, the aphid-virus interaction on susceptible crops is continuous and alternative means of aphid control are required. Lowe (1967b) considered the benefits of changing cereal sowing dates.

Background

Chemical control has normally been used for the control of aphids on field and horticultural crops. Lowe (1958a) reported on the effect of demeton-S-methyl on the cabbage aphid and its predators and Syrett & Penman (1980) examined the effect of a range of insecticides on lucerne aphids and their predators. *Myzus persicae* has become resistant to certain chemicals (G.I. Langford pers. comm.). An effective solution for cabbage aphid damage to oil seed rape is the incorporation of disulfoton at planting, which prevents plant infestations up to flowering and provides increased plant yields (Lammerink & Banfield 1980). In greenhouses the fungus *Verticillium lecanii* (Zimmermann) Veigas has been used effectively for aphid control (Hall & Burgess 1979).

The relatively narrow range of predators and parasitoids on aphids in this country was soon recognised by entomologists and early efforts were made to correct an imbalance in the numbers of aphid species present compared to the small range of exotic predators and parasitoids present. Tillyard (1926b) commented that 'one of the most curious gaps in the New Zealand insect fauna is the complete absence of the green lacewings or Chrysopidae, which are such a valuable check on aphids in other parts of the world.' General aphid predators including ladybirds (Coccinellidae) and lacewings (Chrysopidae) featured highly in the early period of introductions (Dumbleton 1936) and in later considerations (DSIR files, Given 1965). In 1979, Cameron *et al.* (1979) considered that the fauna of aphid predators in Californian lucerne was three to four times more diverse than that in New Zealand.

Since all of the pest aphids in New Zealand are exotic in origin and in the main have arrived as accidental introductions from other countries it is not surprising that some of their natural enemies have arrived in a similar manner. Valentine (1967a) noted the presence of parasitic Hymenoptera in the families Braconidae and Aphelinidae, predators in the families Coccinellidae, Syrphidae, Cecidomyiidae, Hemerobiidae and Nabidae and fungi in the genus *Entomophthora*. He also stated that natural enemies on their own are seldom effective in checking aphid populations. Valentine (1967b) lists the aphid hosts, parasitoids, hyperparasitoids and predators known in New Zealand. The importance of the hyperparasitoids is considered in Valentine (1967a) which stated that 'the Aphidiidae all appear to be parasitised by a number of non-specific hyperparasites'.

Specific introductions of Hymenoptera (Braconidae) were not considered for cabbage and cereal aphid control in New Zealand because *Diaeretiella rapae* (M'Intosh) (Braconidae) was known to be heavily parasitised by the hymenopteran hyperparasitoids, *Dendrocerus niger* (Howard) (Ceraphronidae), *Alloxysta victrix* (Westwood) (Charipidae) and *Pachyneuron siphonophorae* (Ashmead) (Pteromalidae) (Gourlay 1930, Lowe 1968).

Several predators were present prior to introductions, and some of these may have been self introduced. The ladybeetle species, *Coccinella leonina* F. and *Adalia bipunctata* (L.) (Coccinellidae), appear less commonly on cereals and cruciferous crops, the latter being more numerous in arboreal situations. These two species have been present in New Zealand for a very long time. They both occur in Australia and *A. bipunctata* has a wide European and American distribution. It is likely that these ladybirds were accidentally introduced into New Zealand in produce from overseas. Fereday (1872) reported '...two species at least of

the family of the Coccinellidae, commonly called 'ladybirds', or 'lady-cows', whose larvae feed entirely on Aphides.' This statement included cereal and brassica aphids, and probably refers to the predators *C. leonina* and *A. bipunctata*. Both are well established and it appears they have become more common since the establishment of the lucerne and pea aphids *Acyrthosiphon* spp. *Adalia bipunctata* is often associated with various aphids on *Prunus* spp. and *C. leonini* with aphids on herbaceous plants and cereals. These two predators never appear as abundantly in crops as *Coccinella undecimpunctata* L. However, *A. bipunctata* appears not to be parasitised by *Dinocampus coccinellae* in New Zealand, or very rarely so (Thomas unpublished).

Two species of nabid bugs *Nabis capsiformis* Germar and *N. maoricus* Walker feed on cereal aphids but are not common. Predaceous midge larvae (Cecidomyiidae) occasionally feed on these aphids, as do spiders and harvestmen (Phalangiidae), but the importance of these has not been determined. Some of the general predators of aphids in New Zealand are also attacked by parasitoids (Thomas 1977, Valentine 1967a). The common syrphids *Melanostoma fasciatum* (Macquart) and *Melangyna novaezealandiae* (Macquart), recognised by Miller (1918) as predatory on aphids, are both attacked by *Diplazon laetatorius* (F.) (Ichneumonidae). The hemerobiid *Micromus tasmaniae* (Walker) (Hemerobiidae) is parasitised by *Anacharis zealandica* Ashmead (Figitidae) and *Coccinella undecimpunctata* by *Dinocampus coccinellae* (Schrank) (Braconidae).

The insectivorous bird, the 'silver eye', *Zosterops lateralis* (Latham) has been reported as a voracious predator of woolly apple aphid (Myers 1923) and is known to feed on other aphid species as well.

Given (1965) reported the commencement of negotiations with CIBC for a new attempt to import beneficial insects to attack aphids on cereal and cruciferous crops, and Valentine (1975) summarised progress. Emphasis was placed on the introduction of general predators of aphids of which there are few in New Zealand, rather than hymenopterous parasitoids, as existing species were known to be heavily hyperparasitised in most districts (Lowe 1968). Members of two major groups of predators overseas, the Coccinellidae and Chrysopidae, were imported over several years (mainly 1967-1976) but Syrphidae and Chamaemyiidae were also included in consignments (Thomas 1977).

Importations, Releases and Recoveries

The species are grouped within families in the chronological order of their importation.

Coccinellidae (Coleoptera)
Coccinella undecimpunctata L., 11-spotted ladybird

There is little information available on the circumstances of this, probably the first, purposeful introduction into New Zealand of an insect for biological control. Tillyard (1926a) considered that this could possibly have been an accidental introduction, but Gourlay (1930), Dumbleton (1936) and Hagen (1962) report that this introduction took place in 1874. Miller (1964) discussed the source of *C. undecimpunctata* and stated that '...Hutton, then at the Otago Museum, and Nottige, of the Canterbury Acclimatisation Society, secured supplies of the 11-spotted ladybird, together with unspecified lacewings from the Entomological Society of London.' Miller also considered that the species could have been established in New Zealand as early as 1837. The staff of the Department of Agriculture were later responsible for much of the early redistribution of the species within the country once it had become established. This distribution is variously reported by T.W. Kirk and T. Broun in the Annual Reports for the New Zealand Department of Agriculture (1895–1900). The success of this is indicated by the fact that Kirk (1899) reported that he had sent over 300 eleven-spotted ladybirds to Samoa during the year and that he had requested Captain Broun (assistant entomologist in

Auckland) to do likewise. This species is now very widespread throughout lowland New Zealand.

Harmonia conformis (Boisduval)

Tillyard (1926a) reported that this spotted Australian ladybird was introduced in 1896 from New South Wales and in 1898 Kirk sent an additional consignment to New Zealand (Kirk 1898). T. Broun, who received these, indicated that this species was encountered in several places (Kirk 1898) and was probably established. Tillyard (1926a) stated that it appeared to be present throughout the country. This has not been borne out in fact and Dumbleton (1936) correctly reported that it was established only in the Auckland Province. It is a general predator of aphids.

At least two later introductions of the species have also been made. In March 1964 H.C. Smith forwarded a consignment of adults from Australia (C.T. Jessep unpublished). These were used for feeding tests with *B. brassicae*, a species which was not favoured by this predator. Two hundred adults were released in Cashmere (Christchurch) but there is no evidence of establishment of the species from releases made at that time in Canterbury.

H. conformis from Tasmania appeared as a contaminant of coccinellids consigned to R. Zondag in 1976 (DSIR files) and 40 adults were sent to Auckland for rearing (R.L. Hill pers. comm.). Although differing slightly from the *H. conformis* known from Auckland they were considered to be conspecific (C. Watt pers. comm.). They fed actively on pea aphid. Releases were made in Auckland and a population reared in quarantine was forwarded to Lincoln where rearing and release of the species continued. There is no evidence that they became established in Canterbury.

Coccinella transversoguttata Falderman and *Cycloneda munda* (Say) (= *Coccinella californica* Mannerhinn) and (= *Cycloneda sanguinea* (L.))

Tillyard (1926a) stated that A. Koebele introduced into New Zealand these two species from California in 1889. Dumbleton (1936) also reported these introductions, but both species apparently failed to become established.

Hippodamia convergens (Guérin)

This species was reportedly first introduced in 1899 (Tillyard 1926a) by the Department of Agriculture, but failed to become established. A large consignment comprising 27,000 adults was forwarded to the Cawthron Institute in September 1921 by H. Smith of the Pest Control Service of Sacramento. Eleven thousand of these survived and according to E.S. Gourlay (unpublished report 1929 DSIR files) these were distributed in lots of 50 to applicants in Nelson, with smaller numbers being sent to Auckland, Hastings, New Plymouth, Blenheim, Christchurch and Dunedin, where they were placed out on various host trees. There is no evidence that this species became established.

Micraspis frenata (Erichson)

M. frenata was introduced from Australia in February 1964 when 36 adults and 18 larvae were received from H.C. Smith. These were reared on *Brevicoryne brassicae* by C.T. Jessep for a short period before being released. Eggs obtained initially from these were used in feeding tests in which a generation at room temperature took about 34 days. Three hundred adults of this species were released at Cashmere (Christchurch) in 1964. No establishment occurred.

Oenopia sauzeti Mulsant

The introduction of this species commenced the second phase of general aphid predator introductions. The first of many consignments was received from M.A. Ghani, Pakistan Station CIBC, in December 1968 (Table 11.1). During the period 1968-76 many thousands of eggs, larvae and adults were reared on various aphid species, but mainly *R. padi*, on greenhouse-raised cereals. A total of approximately 20,000 (all stages) was released during 1968-76 in the vicinity of Christchurch. More than 15,000 eggs, larvae and adults were released north of Auckland in Kerikeri, Paihia and near Auckland. Although these persisted through several generations following release, this species failed to become established.

Coccinella septempunctata L.

Hodek (1973) stated that *C. septempunctata* was native to much of Asia, Europe, and North Africa. The species is very important as a general predator of aphids in Europe. Like *C. undecimpunctata* it is commonly attacked by the parasitoid *Dinocampus coccinellae*. Angalet *et al.* (1979) described the early releases and attempts to establish this species in the U.S.A. in 1956. *C. septempunctata* was recovered in one area of New Jersey in 1973 and 1974 and from the established colonies the species has been redistributed successfully to other areas.

Negotiations for importation of this species to New Zealand were commenced with M.A. Ghani of the Pakistan Station of CIBC in 1969, and major consignments were received during the period 1970-1973. Several thousand adults were imported, checked in quarantine and major releases made at Lincoln in field cages onto aphid infested brassicas. Despite the temporary establishment of this species at release sites in Canterbury and elsewhere, the species was not permanently established.

In 1975 and 1976, G.K. Scheibelreiter of the Austrian sub-station of CIBC forwarded field-collected populations of *C. septempunctata*. These were held in quarantine then used for laboratory rearing and field release of offspring. No establishment occurred.

Two consignments of *C. septempunctata* comprising 200 and 400 adults were sent to T. Bourke in Western Samoa in April and June 1978 (DSIR files). It is believed not to have established there (P.A. Maddison pers. comm.). Hibernating aggregations have been intercepted on machinery parts brought into New Zealand from Europe during the late 1970s, but attempts to establish permanent breeding populations from these failed.

Harmonia dimidiata (F.)

Adults of this species were collected near Swat in Pakistan and reared in the laboratory. M.A. Ghani forwarded the first consignment in July 1974, two shipments in November of the same year, and another in 1976. Most individuals were of the form in which the elytra are predominantly black, but some of those of the final consignment were of the spotted type in which orange predominates (i.e. orange elytra with black spots). The latter according to H. Sasaji (DSIR files) is the common form in Japan (Miyatake 1965) where conditions are somewhat cooler, but Ghani (DSIR files) rarely encountered the spotted form at Swat.

This very voracious feeder was easily raised in the laboratory on a wide range of aphid species. First generation adults and several thousand eggs were released at Lincoln in September 1974. During the next two years releases were made at Kerikeri, Auckland, Tauranga, Palmerston North, Woodhill, Nelson and Canterbury. Overwintering aggregations were noted on young *Pinus radiata* trees at Lincoln in 1975 and again in 1976. A *Thuja orientalis* L. tree which annually attracted overwintering aggregations of *C. undecimpunctata*, was also attractive to *H. dimidiata* released at least one half kilometer away. Despite many thousands of individuals being reared and released in various parts of the country, this species has not become established. In 1978 two consignments of this species were sent to T. Bourke in Western Samoa (DSIR files). It is believed that they have not become established there (P.M. Maddison pers. comm.).

Table 11.1

Aphid predators, Neuroptera, Coleoptera, Diptera, introduced into New Zealand

Family & species	Country of origin	Year	Number imported	Number released	Locality	Comment
COLEOPTERA: COCCINELLIDAE						
Coccinella undecimpunctata L.	Europe	1874	?	?	?	Established, common
Harmonia conformis (Boisduval)	Australia	1886	200	?		Estab. Auckland Province
	Australia	1888	200	?		Estab. Auckland Province
	Australia	1964	?	200	Canterbury	Not established
	Tasmania	1977	40+	200+	Canterbury	Not established
				Hundreds	Auckland	1978-81 ? established
Cycloneda munda (Say)	U.S.A.	1889	?	?	?	Not established
Coccinella transversoguttata Falderman	U.S.A.	1889	?	?	?	Not established
Hippodamia convergens (Guérin)	U.S.A.	1889	?		Many	Not established
		1921	27000		(Predominantly Nelson)	Not established
Micraspis frenata (Erichson)	Australia	1964	36 adults, 18 larvae	300	Canterbury	Not established
Oenopia sauzeti Mulsant	Pakistan	1968-76	Many	Thousands	Various	Recovered
Coccinella septempunctata L.	Pakistan	1970-73	Many	Thousands	Various	Recovered
	Austria	1975-76		Hundreds	Various	Recovered
Harmonia dimidiata (F.)	Pakistan	1974-76	Many	Thousands	Various 1974-81	Not established
Coccinella repanda Thunberg	Victoria, Australia	1978	96	Nil	-	Culture died in quarantine
NEUROPTERA: CHRYSOPIDAE						
Chrysopa sp. (1)	Australia		About 100	100+	Nelson	Not established
	Australia	1921	?			
Chrysoperla plorabunda (Fitch)	U.S.A.	1922	25	Nil	-	Culture died out
	U.S.A.	1925	90	Nil	-	Dead on arrival
	U.S.A.	1926	15	Nil	-	Dead on arrival
Chrysoperla oculata Say	U.S.A.	1925	?	?	?	-
	U.S.A.	1926	16 pupae 5 larvae	-	-	Attempts to culture these failed
Chrysopa sp. (2)	B. Columbia	1925	1910	650	Nelson	Not established
				650	Chch	Not established
	B. Columbia	1927	540 adults	800	Nelson	Not established
			1050 eggs	250	Chch	Not established
Chrysopa sp. (3)	B. Columbia	1927	227 pupae	622	Nelson	Not established
Chrysopa ramburi Schneider	California, U.S.A.	1928	21 pupae	Nil	-	Attempts to culture these failed
Chrysopa spp. (4,5,6)	Australia	1969	Few	Few, 1 sp.	Nelson	Not established
Chrysopa nigricornis Burmeister	U.S.A.	1972	18 pupae	Nil	-	Attempts to culture these failed
Chrysoperla carnea (Stephens)	California, U.S.A.	1968 & 1970	? eggs	Thousands	Various	Not established
	Pakistan	1969	Few			Bred with California strain but failed to establish

Family & species	Country of origin	Year	Number imported	Number released	Locality	Comment
NEUROPTERA: CONIOPTERYGIDAE						
Conwentzia psociformis (Curtis)	N. America	1924	Few	Few	Nelson	Not established
NEUROPTERA: HEMEROBIIDAE						
Sympheriobius barberi (Banks)	? N. America	?	?	?	?	
Sympheriobius californicus (Banks)	? N. America	?	?	?	?	
DIPTERA: CHAMAEMYIIDAE						
Leucopis nigricornis Egger, *L. obscura* Haliday, *L. puncticornis* (Meigen)	Pakistan	1969-70	900	?	Caged at Lincoln	Failed to breed
DIPTERA: SYRPHIDAE						
Metasyrphus confractor (Wiedemann), *Episyrphus ?balteatus* Degeer, *Scaeva pyrastri* (L.)	Pakistan	1969-71	1119 pupae	-	-	Failed to breed

Coccinella repanda Thunberg

This species was introduced to Lincoln in September 1977 by courtesy of the Victorian State Department of Agriculture from field collections made in Australia in 1978. Some adult beetles were destroyed through cannibalism but most were received in apparently healthy condition. However, during quarantine rearing high levels of mortality accompanied the emergence of *Dinocampus coccinellae*. Anderson *et al.* (1986) reported a mean parasitism rate of 27% for this species in Australia. Few first generation offspring were obtained because of rearing problems. An unidentified mortality factor destroyed virtually the whole of the fourth generation (over 400) offspring in quarantine and none were released. The identity of this factor could not be isolated.

Chrysopidae

Chrysopa sp. (1)

The first green lacewings to be introduced into New Zealand were species of *Chrysopa* introduced from Australia in October (45 adults and 68 eggs) and November 1921 (unknown numbers) (E.S. Gourlay unpublished report DSIR files). Reference is made to the larvae of this species, which disguise themselves with pieces of leaf and detritus. More than 100 offspring were released in Nelson, but there is no record of establishment.

Chrysoperla plorabunda (Fitch)

In April 1922, 25 *Chrysoperla plorabunda* were received by the Cawthron Institute from R.C. Smith, Kansas, U.S.A. The four surviving females produced eggs in May of the same year, but cannibalism amongst individuals led to the demise of the colony and none were released. A second consignment of 90 adults from H. Smith (California) was received in November 1925, but these were all dead on arrival. The third consignment of 15 adults was received in January 1926 but again none of these survived the sea journey from the U.S.A.

Chrysoperla oculata Say

An unspecified number of immature *C. oculata* were received with the *C. plorabunda* in November 1925, but there is no indication as to what happened to this consignment. A further consignment in January 1926 contained five larvae and 16 pupae. Attempts to rear these failed and none were released.

Chrysopa sp. (2)

In December 1925 a consignment of 1,910 hibernating adults of *Chrysopa* sp. was also received by the Cawthron Institute, from W. Downes and A. Gibson, Department of Agriculture, Victoria, British Columbia, in Canada (E.S. Gourlay DSIR files, Tillyard 1926a). Approximately 650 of the survivors were released in Nelson, 650 in Christchurch (by A. Tonnoir) and 600 were kept for breeding purposes. Details of the rearing at the Cawthron Institute are provided in Gourlay's report. As a result of the rearing programme, several hundred adults were released at Wakefield and Nelson. None of these became established (E.S. Gourlay DSIR files).

A second consignment was received in January 1927. From the 535 survivors more than 1,000 eggs were obtained of which 250 were sent to Christchurch for release on aphid-infested oak trees. The remainder were caged on wild cotton plants in Nelson. Few adults were produced in the first generation, most of the eggs produced were infertile and the colony was lost.

Chrysopa sp. (3)

In October 1927, 227 cocoons of a second field-collected *Chrysopa* sp. were received from Downes. These were held in a laboratory to screen out the undesirable parasitoids. The *Chrysopa* sp. adults emerged over the course of a full year. Two hundred and seventeen first generation larvae were released onto pine trees amongst '*Chermes*' sp. populations in Nelson in March 1927, and 310 in April and 95 in May. The species did not become established from these liberations.

Chrysopa ramburi Schneider

In 1928, 21 cocoons of this species were received in Nelson in December, from H. Compere of the University of California. Ten adults emerged but these soon died and no eggs were obtained.

Chrysopa spp.

Three unidentified species of *Chrysopa* collected by W.P. Thomas in Victoria, Australia were introduced into Nelson in March 1969. These were collected from apple trees, and were very large and voracious feeders. E.W. Valentine (DSIR files) successfully reared two of these species and one of them was released in Nelson in 1969. Small lepidopterous larvae were used to supplement the diet of *Neotoxoptera violae* (Pergande) (onion aphid) used for rearing. Establishment of the one species released was not successful.

Chrysoperla carnea (Stephens)

Following a successful rearing programme for this species in the U.S.A. *Chrysoperla carnea* was obtained as eggs from K.S. Hagen in California in October 1968, and again in April 1970. The Californian strain of this species was successfully reared at Nelson, Auckland, and Lincoln during the period 1968-1972, using various aphid species, 'Food Wheast', ant larvae, or lepidopterous larvae. Many thousands (including eggs, larvae, and adults) were released during this time span, but this species has not become established.

In 1969, small numbers of this species were obtained from M.A. Ghani, CIBC Pakistan Station, and reared at Lincoln. Again, successful colonies were raised and releases made near Lincoln, Auckland, and North Auckland. Field establishment was not achieved.

Chrysopa nigricornis Burmeister

A small consignment of 18 *Chrysopa nigricornis* cocoons was received in Entomology Division in Nelson in May 1972 from K.S. Hagen, but attempts to rear this species failed because of infertility of eggs (DSIR files).

Hemerobiidae (Neuroptera) *Sympherobius barberi* (Banks) and *Sympherobius californicus* (Banks)

Dumbleton (1936) reported that these two species of lacewings were introduced into New Zealand for aphid control. There is very little information available in respect to these introductions except that Kirk (1895) points to the fact that A. Koebele collected beneficial insects in the U.S.A. for transfer to New Zealand. It is probable that they were released but there is no record of their establishment.

Coniopterygidae (Neuroptera) *Conwentzia psociformis* (Curtis)

In 1924 a few cocoons of *Conwentzia psociformis* were received by the Cawthron Institute from A. Koebele in North America. A few were released in Nelson but the species did not become established (Dumbleton 1936).

Chamaemyiidae (Diptera) *Leucopis nigricornis* Egger, *L. obscura* Haliday, and *L. puncticornis* (Meigen)

Three species of Chamaemyiidae were introduced from the Pakistan Station of CIBC (Thomas 1977). The first consignment from M.A. Ghani arrived in 1969, but most flies died during transit. Further consignments containing 350 and 332 pupae arrived in April and May 1970. Healthy flies were field-released into cages at Lincoln but, in a declining aphid population, these insects failed to lay eggs and died out. A later consignment was destroyed because of the high levels of parasitism (C.T. Jessep pers. comm.).

Syrphidae (Diptera) *Metasyrphus confractor* (Weidemann), *Episyrphus ?balteatus* Degeer, *Scaeva pyrastri* (L.)

These syrphid species were received in consignments from M.A. Ghani in October 1969, March 1970, April 1970 and April 1971. The consignments comprised 494, 275 and 350 pupae. Parasitism of the pupae was high and few healthy flies were reared. It was not possible to obtain high rates of mating success with these species in quarantine (C.T. Jessep pers. comm.).

Evaluation

Coccinella undecimpunctata is now very widespread throughout low-land New Zealand and can be easily collected during the summer and autumn months. It is the most abundant coccinellid in field crops and can occasionally decimate aphids in lucerne (Cameron *et al.* 1979). However, it is rare in spring aphid populations and provides unpredictable control in summer and autumn. In studies conducted in the mid-1970s near Lincoln, this species was found to hibernate from April to September. High numbers commonly hibernated on *Thuja orientalis* L. and groups occurred under the calyces adjoining developing seed pods of kowhai *Sophora tetraptera* J. Miller, among needles on the lateral shoots of *Pinus radiata* D. Don, and under loose bark or within cracks of old wooden fence posts on the Canterbury Plains. This species seeks out the same overwintering sites from year to year, as noted also by Hodek (1973) for some other species.

There are two main mortality factors which may limit populations of *C. undecimpunctata*. The fungus *Beauveria bassiana* (Balsamo) Vuillemin caused 56% to over 90% mortality in overwintering aggregations of adults in unfavourable wet weather conditions, but this was not a significant mortality factor under cold, dry winter conditions (Thomas unpublished). All populations studied in Canterbury during the same period were heavily parasitised in winter and from mid-summer onwards by *Dinocampus coccinellae*. Thomas (unpublished) noted around 85% parasitism of Canterbury populations and this is similar to that reported by Townsend (1980) and Early (1984).

Harmonia conformis has not been evaluated in New Zealand. It is relatively common in the Auckland Province, but does not appear to have been as generally distributed as suggested

by Tillyard (1926a). The species is attacked by *Dinocampus coccinellae* in Australia, but information is not available for New Zealand. Its present distribution in this country appears to be determined by climatic factors.

Most of the introductions of *Chrysopa* spp. carried out in the 1920s resulted in the release of few individuals. This is likely to have severely limited their prospects for establishment. The later importation of *Chrysoperla carnea* was followed by successful rearing and the releases of large numbers. Valentine (1975) suggested that *C. carnea* failed because it was unable to adapt to New Zealand conditions. By contrast, the resident brown lacewing *Micromus tasmaniae*, with its relatively low developmental temperature threshold (Syrett & Penman 1981), appears well adapted to the climate.

During the second phase of the general aphid-predator programme, there was much greater success with rearing and larger releases were made. Each of the major species, *Chrysoperla carnea*, *Oenopia sauzeti*, *Coccinella septempunctata* and *Harmonia dimidiata* were reared very satifactorily in the laboratory on aphids of field crops prior to their release. However, none of these species survived more than one or two generations in the field. The reasons why they failed to become established at least at some of the release sites are unknown. Part of the problem for the coccinellids may be related to the lack of a continuous source of host aphids at a level sufficient to sustain predator populations. In many instances aphid populations declined at the release sites and this was followed by dispersal and loss of the predators. Populations of *C. septempunctata* were not detected again following these migrations. Hibernating populations of *H. dimidiata* were located, but these were heavily parasitised.

Failures to establish coccinellids are not uncommon. Clausen (1978) reported that *Hippodamia convergens* has become established only in Peru, although it was shipped from North America to 11 other countries. He considered that wide dispersal following hibernation and lack of suitable hibernation sites may be the principal difficulties.

Parasitism may also have contributed to establishment failure. Since *C. undecimpunctata* became established in the presence of high levels of parasitism it is not likely that lack of establishment of other predators is attributable to this factor alone. In New Jersey, when *C. septempunctata* was eventually established, Cartwright *et al.* (1982) recorded the level of parasitism by *D. coccinellae* as around 11%. However, in New Zealand the levels of parasitism of the 11-spotted ladybird are very much higher (Thomas unpublished, Early 1984). At one release site in Canterbury the prospects for establishment of *Harmonia dimidiata* were clearly limited when all the adults sampled (35), had become parasitised by *D. coccinellae* within a three week period following their release.

Conclusions

In any future considerations given to the biological control of aphids it would be worthwhile considering the importation of additional parasitoids since these have been established successfully on other aphid species in New Zealand. Despite the establishment of *C. undecimpunctata* and *H. conformis* it would be advantageous to have a greater range of aphid predators in New Zealand. A recommended pre-requisite of any future introductions of aphid predators would be to obtain them from climatic zones similar to those of New Zealand. A range of species which may have potential for introduction against aphids of graminaceous crops is discussed in CIBC (1977). The world wide difficulties encountered by biological control workers attempting to establish Coccinellidae and Chrysopidae suggest that the problems may not be related to the particular species, but rather to these families as a whole. Therefore, new attempts should not necessarily concentrate on new species, but greater attention should be given to the development of methods to overcome losses associated with emigration and hibernation.

Acknowledgments

The author wishes to thank C.T. Jessep in providing much of the information and those persons who have assisted in the release of aphid predators in the past.

Literature Cited

Anderson, J.M.E.; Hales, D.P.; van Brunschot, K.A. (1986) Parasitisation of coccinellids in Australia. Pp. 519-524 in Hodek, I. (ed.), Ecology of Aphidophaga. Academia, Prague.

Angalet, G.W.; Tropp, J.M.; Eggert, A.N. (1979) *Coccinella septempunctata* in the United States: recolonizations and notes on its ecology. *Environmental entomology* 8, 896-901.

Burnett, P.A. (1984) Cereal crop pests. Pp. 153-163 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Cameron, P.J.; Thomas, W.P.; Hill, R.L. (1979) Introduction of lucerne aphid parasites and a preliminary evaluation of the natural enemies of *Acyrthosiphon* spp. (Hemiptera: Aphididae) in New Zealand. Pp. 219-223 in Crosby, T.K.; Pottinger, R.P. (eds), *Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology*, Government Printer, Wellington.

Cartwright, B.; Eikenbary, R.D.; Angalet, G.W. (1982) Parasitism by *Perilitus coccinellae* (Hym.: Braconidae) of indigenous coccinellid hosts and the introduced *Coccinella septempunctata* (Col.: Coccinellidae), with notes on winter mortality. *Entomophaga* 27, 237-244.

CIBC (1977) Possibilities of biological control of aphids of graminaceous crops. CIBC Status Paper No 4 (revised 1981), 10 pp.

Cottier, W. (1953) The aphids of New Zealand. *Bulletin of New Zealand Department of Scientific and Industrial Research* 106, 383 pp.

Clausen, C.P. (1978) Aphididae. Pp. 35-46 in Clausen, C.P. (ed.), Introduced parasites and predators of arthropod pests and weeds: a world review. *Agricultural Research Service, United States Department of Agriculture, Agriculture Handbook* 480.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Early, J.W. (1984) Parasites and predators. Pp. 271-308 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Fereday, R.W. (1872) On the direct injuries to vegetation in New Zealand by various insects, especially with reference to larvae of moths and beetles feeding upon the field crops; and the expediency of introducing insectivorous birds as a remedy. *Transactions of the New Zealand Institute* 5, 289-294.

Given, B.B. (1965) Biological control of insect pests and noxious weeds. *Proceedings of the 18th New Zealand Weed and Pest Control Conference*, 223-228.

Gourlay, E.S. (1930) Preliminary host list of the entomophagous insects in New Zealand. *New Zealand Department of Scientific and Industrial Research bulletin* 22, 13 pp.

Hagen, K.S. (1962) Biology and ecology of predacious Coccinellidae. *Annual review of entomology* 7, 289-326.

Hall, R.A.; Burgess, H.D. (1979) Control of aphids in glasshouses with the fungus, *Verticillium lecanii*. *Annals of applied biology* 93, 235-246.

Hodek, I. (1973) Biology of the Coccinellidae. Dr W. Junk, N.V. The Hague. 260 pp.

Kirk, T.W. (1895) *The third report of New Zealand Department of Agriculture*, p. 158.

Kirk, T.W. (1898) *The sixth report of New Zealand Department of Agriculture*, p. 198.

Kirk, T.W. (1899) *The seventh report of New Zealand Department of Agriculture*, p. 234.

Lammerink, J.; Banfield, R.A. (1980) Effect of aphid control by disulfoton on seed yield components and seed quality of oil seed rape. *New Zealand journal of experimental agriculture* 8, 45-48.

Lange, W.H. (1987) Insect pests of sugar beet. *Annual review of entomology* 32, 341-360.

Lowe, A.D. (1958a) Effect of 'Metasystox' on the cabbage aphid (*Brevicoryne brassicae* (L.)). *New Zealand journal of agricultural research* 1, 37-43.

Lowe, A.D. (1958b) Insect pests of brassicas. *Proceedings of the 8th Lincoln College Farmers' Conference*, 111-120.

Lowe. A.D. (1967a) Aphids on crops in New Zealand. *Proceedings of the 20th New Zealand Weed and Pest Control Conference*, 185-196.

Lowe, A.D. (1967b) Sowing date as an aphid-virus control technique. *Proceedings of the 20th New Zealand Weed and Pest Control Conference*, 214-216.

Lowe, A.D. (1968) The incidence of parasitism and disease in some populations of the cabbage aphid (*Brevicoryne brassicae* L.) in New Zealand. *New Zealand journal of agricultural research* 11, 821-828.

Lowe, A.D. (1973) Aphid biology in New Zealand. Pp. 7-19 in Lowe, A.D. (ed.), Perspectives in aphid biology. Bulletin No. 2. The Entomological Society of New Zealand (Inc.).

McLaren, G.F. (1968) The development of life tables for studying the population dynamics of the cabbage aphid *Brevicoryne brassicae* (L.). M.Hort.Sci. thesis, Lincoln College, University of Canterbury. 199 pp.

McLaren, G.F. (1975) The population dynamics of the cabbage aphid, *Brevicoryne brassicae* (L.), in Central Otago, New Zealand. Ph.D. thesis, Lincoln College, University of Canterbury. 266 pp.

Miller, D. (1918) The economic bearing of hover-flies. *New Zealand journal of agriculture* 17, 129-135.

Miller, D. (1964) Historical synopsis of biological control practice in New Zealand. *New Zealand science review* 22, 4-6.

Miyatake, M. (1965) Some Coccinellidae (excluding Scyminini) of Formosa (Coleoptera). *Special bulletin of the Lepidopterist's Society of Japan* 1, 50-75.

Myers, J.G. (1923) The relation of birds to agriculture in New Zealand. III. The larger fruit and insect-eating perching-birds (Passeres). *New Zealand journal of agriculture* 27, 13-19.

Smith, H.C. (1963) Spraying for control of yellow dwarf virus in wheat. *Proceedings of the 13th Lincoln College Farmers' Conference*, 102-109.

Swenson, K.G. (1973) Insects as vectors of plant viruses and mycoplasma like organisms. Pp. 92-102 in Lowe, A.D. (ed.), Perspectives in aphid biology. Bulletin No. 2. The Entomological Society of New Zealand (Inc.).

Syrett, P.; Penman, D.R. (1980) Studies of insecticide toxicity to lucerne aphids and their predators. *New Zealand journal of agricultural research* 23, 575-580.

Syrett, P.; Penman, D.R. (1981) Development threshold temperature for the brown lacewing, *Micromus tasmaniae* (Neuroptera: Hemerobiidae). *New Zealand journal of zoology* 8, 281-283.

Thomas, W.P. (1977) Biological control of the blue-green lucerne aphid. The Canterbury situation. *Proceedings of the 30th New Zealand Weed and Pest Control Conference*, 182-187.

Tillyard, R.J. (1926a) History of the introduction of beneficial insects into New Zealand. *Proceedings of the Pan Pacific Science Congress* 1, 383-390.

Tillyard, R.J. (1926b) The progress of economic entomology (with special reference to Australia and New Zealand). *Journal of the Royal Society of Arts*, 3-17.

Townsend, P. (1980) Toxicity studies of insecticides on lucerne aphids and their predators. M.Agr.Sc. thesis, University of Canterbury, Lincoln College, 119 pp.

Travers, W.T.L. (1864) Additional observations on the diffusion of European weeds and their replacement of the indigenous vegetation in New Zealand. *Natural history review* 16, 617-619.

Valentine, E.W. (1967a) Biological control of aphids. *Proceedings of the 20th New Zealand Weed and Pest control Conference*, 204-207.

Valentine, E.W. (1967b) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1209.

Valentine, E.W. (1975) Current projects on biological control of insects. *Proceedings of the 28th New Zealand Weed and Pest Control Conference* 193-195.

Chrysodeixis eriosoma (Doubleday), green looper (Lepidoptera: Noctuidae)

L.I.N. ROBERTS and P.J. CAMERON

Pest Status

Chrysodeixis eriosoma (Doubleday), the green looper caterpillar or silver Y moth, is found throughout Asia, in Indonesia, New Guinea, Australasia (Dufay 1973) and on Cook, Niue, Rapa, and a number of other islands in the Pacific (Dugdale 1972). In New Zealand, it is distributed throughout the North Island and in the northern half of the South Island (Roberts 1979). Until Kostrowicki (1961) revised the Plusiinae subfamily of the family Noctuidae (Phalaenidae), this moth was recorded in New Zealand as *Plusia chalcites* (Esper). Hudson (1898) and Watt (1915) considered it an indigenous New Zealand species whose original food plant was *Solanum aviculare* G. Forster (poroporo), whereas Gaskin (1966) and Fox (1978) considered it to originate from Australia and to be supplemented by continual migration.

Three other Plusiinae have been recorded in New Zealand, all migrants from Australia (Dugdale 1968, Fox 1972, 1978, Hill *et al.* 1987). *Chrysodeixis argentifera* (Guenée), the tobacco looper, occasionally becomes a serious pest on tobacco and tomatoes around Nelson and Motueka, but does not appear to be able to survive the winter (Fox 1970). *Ctenoplusia albostriata* (Bremer & Grey) is well established but has a very restricted diet, feeding only on *Erigeron* spp. and a few *Aster* spp. *Thysanoplusia orichalcea* (F.) was first recorded in New Zealand in 1984 and since then appears to have become well established in the northern parts of the North Island. It is polyphagous, though with a slightly different host range from *Chrysodeixis eriosoma* and could become a significant defoliating pest in legumes and brassicas (Hill *et al.* 1987).

The *C. eriosoma* larva is polyphagous, feeding predominantly on plants in the Solanaceae, Asteraceae and Fabaceae. Leaves, flowers, and sometimes fruit are eaten and it is a pest on a variety of cultivated annuals such as tomato, beans, pumpkin, capsicum and tobacco (Roberts 1979). Cameron *et al.* (1986) calculated that the economic threshold on soybeans at seed enlargement stage was 28% defoliation or 22 looper larvae per metre. This level is not reached by *C. eriosoma* alone but may be reached in combination with the newly arrived *T. orichalcea*.

Caterpillars of all ages can be found throughout the year in the warmer parts of New Zealand, though in considerably reduced abundance between May and November. Over winter the principal food plants are perennials such as geranium, buddleia, borage and morning glory vine and in early spring plants such as cineraria and black nightshade are important hosts. Moths can be caught in light traps in considerable numbers in the months January to March but only spasmodically from May to December. Approximately five generations occur per year in the Auckland region (Roberts 1982); further south seasonal occurrence is more marked and the number of generations is reduced. Roberts (1979) describes *C. eriosoma* biology in New Zealand.

Background

Nine naturally occurring parasitoids of *C. eriosoma* have been recorded in New Zealand, of which two appear to have been self introductions from Australia. The most common, prior to importations of noctuid parasitoids, were the egg parasitoids *Trichogrammatoidea bactrae* Nagaraja and *Trichogramma (Trichogrammanza) funiculatum* Carver (see Chapter 21).

Three naturally occurring larval parasitoids have been recorded (see Table 12.1). The most common of these is the gregarious braconid *Apanteles ruficrus* which Valentine (1967) records as a parasitoid of *C. eriosoma* in New Zealand prior to the importation of a new strain from Pakistan (see below). The solitary braconid *Microgaster* (= *Microplitis*) sp., a parasitoid of young larvae, is found throughout the North Island and as far south as Christchurch (Roberts 1982). Although it is usually found infrequently, significant rates of parasitism are occasionally recorded. For example, two samples, each of 61 second and third instar larvae, collected in an Auckland garden in January and February 1979 showed parasitism rates of 18% and 15% respectively (Roberts 1982, unpublished data). The solitary parasitoid *Rogas* sp. is a rare parasitoid of young larvae (Hill *et al.* 1985, Valentine 1967).

Three pupal parasitoids have been recorded (see Table 12.1). The two ichneumonids *Echthromorpha intricatoria* (F.) and *Ctenochares bicolorus* (L.) are both thought to have been self introduced from Australia, the latter around 1981 (Fitton *et al.* 1983). *E. intricatoria* is a parasitoid of a range of lepidopteran pupae (Valentine 1967). Of the 55 *Chrysodeixis eriosoma* pupae collected by Roberts (1982) between Auckland and Christchurch 1979-1982, 15 were parasitised by *E. intricatoria*, and the tachinid *Pales feredayi* (Hutton) was recorded on one occasion.

Table 12.1 Parasitoids of *Chrysodeixis eriosoma* in New Zealand

EGG PARASITOIDS
Trichogrammatoidea bactrae Nagaraja (Trichogrammatidae)
Trichogramma (Trichogrammanza) funiculatum Carver (Trichogrammatidae)
EGG LARVAL PARASITOID
Copidosoma floridanum (= *Litomastix maculata*) Ashmead (Encyrtidae)
LARVAL PARASITOIDS
Apanteles (= *Cotesia*) *ruficrus* Haliday (Braconidae)
Microgaster (= *Microplitis*) sp. (Braconidae) *Rogas* sp. (Braconidae)
LARVAL-PUPAL and PUPAL PARASITOIDS
Ctenochares bicolorus (L.) (Ichneumonidae)
Echthromorpha intricatoria (F.) (Ichneumonidae)
Pales feredayi (Hutton) (Tachinidae)

Importations, Releases and Recoveries

Trichogramma species (Hymenoptera: Trichogrammatidae)

Four species of *Trichogramma* parasitic on noctuid eggs were imported from India in 1974 (Cameron *et al.* 1987) (see Chapter 21).

Copidosoma floridanum (Ashmead) Hymenoptera: Encyrtidae)

In March 1969, W.P. Thomas of Entomology Division, DSIR, collected ten *Chrysodeixis argentifera* Guénée larvae from Noble Park, Victoria, Australia, which were parasitised by a species of *Copidosoma* (= *Litomastix*) (W.P. Thomas pers. comm., Valentine 1975). These ten larvae were shipped to Nelson, New Zealand, and the emerging parasitoids reared in quarantine then released in the Nelson region. In 1970, releases were made in Auckland, Hamilton and Lincoln.

With confirmed establishment at Auckland in 1973, a large scale breeding programme was initiated and the species released at more than 100 sites throughout the Auckland and Wellington provinces and in Christchurch (Valentine 1975). Establishment was soon con-

firmed throughout the North Island and in the Nelson province (DSIR files and personal observations). Establishment in Christchurch was not confirmed until March 1982 following further releases in 1979 (W.P. Thomas pers. comm.).

This polyembryonic species was identified initially as *Litomastix maculata* Ishii, a name recently synonymised with *Copidosoma floridanum* (Ashmead) (Noyes 1988). Further to this, J. Noyes (pers. comm.) believes that all records of *Copidosoma* (= *Litomastix*) *truncatellum* (Dalman) as a parasitoid of plusiine Lepidoptera are misidentifications of *C. floridanum*.

Copidosoma floridanum is a polyembryonic species which lays its egg within the egg of the host. The parasitoid egg proceeds to divide into many embryos which continue to develop within the larva of the host, not completing their development until the host has reached its last instar and spun its cocoon.

Apanteles ruficrus (Haliday) (Hymenoptera: Braconidae)

Shipments of a new strain of *A. ruficrus* reared on *Agrotis ipsilon* (Hufnagel) in Pakistan were received in 1971 and reared in the laboratory on *A. ipsilon* and *Mythimna separata* (Walker). Releases began in 1971 (Cumber *et al.* 1977, Chapter 19). The parasitoid established immediately on *M. separata* and was recovered during a survey of noctuid larvae in 1975-76 from *A. ipsilon* and *Chrysodeixis eriosoma* (Hill *et al.* 1985).

Evaluation

Copidosoma floridanum This parasitoid achieves very high levels of parasitism in the late summer/early autumn in situations where hosts are present throughout the year. In plots of the perennial food plant comfrey (*Symphytum x uplandicum* Nyman), Roberts (1982) recorded 30% parasitism of the first spring generation (early October – early December), 70% in the second main generation (early/mid December – late January) and 93% in the third generation (early February early March). The fourth generation (early March – mid April) and the fifth generation (which overwinters as larvae and emerges as adults late September/early October) also showed high parasitism (84-100% in both years of the study).

C. floridanum overwinters in the host larvae, but at low temperatures parasitised hosts grow more slowly than unparasitised hosts (Roberts 1982). Wasps therefore emerge up to one month after the first moths in spring and consequently the first spring generation of the host largely escapes parasitism, allowing host numbers to build up. Larvae developing from eggs laid in late autumn and early winter also showed reduced parasitism, presumably because the wasps are less active at lower temperatures (Stoner & Weeks 1976) and because parasitised larvae experience higher mortality than unparasitised hosts at low temperatures (Roberts 1982). Collections of larvae in Auckland in September 1978 and September 1981, which had developed from eggs laid in late autumn, showed mean parasitism levels of 66% and 65% respectively. Summer parasitism levels in the same area ranged from 85-100% (Roberts 1982). The parasitoid's reduced activity in late autumn, higher winter mortality and slower winter development, mean that even in stable sites it does not achieve significant levels of parasitism until mid-summer.

In the more disturbed sites represented by commercial crops, much lower levels of parasitism have been recorded. In a survey of a variety of horticultural and agricultural crops in Northland, Auckland and the Waikato conducted January - May 1976 by Hill *et al.* (1985), mean parasitism of *Chrysodeixis eriosoma* by *Copidosoma floridanum* was 38% with a maximum of 72%. In soybeans, Hill *et al.* (1987) recorded 17% parasitism of *Chrysodeixis eriosoma* in February and March 1985, while P.J. Cameron (unpublished data) recorded mean parasitism levels in soybeans in the Waikato of 8%, 14% and 19% in samples of *C. eriosoma* taken in January and February 1980, 1981 and 1982 respectively.

The economic threshold for *C. eriosoma* depends on whether the crop is cultivated for its leaves (e.g. tobacco, mint, poroporo) or its fruit or seeds (e.g. soybeans, tomato,

pumpkin). In soybeans, Cameron *et al.* (1986) established that the economic injury level for looper caterpillars was 22 larvae per metre of row. Since larvae parasitised by *Copidosoma floridanum* consume 72.9% more leaf area than unparasitised larvae (Roberts 1982), the level of parasitism will have a considerable effect on the economic threshold. If population levels have not changed, parasitism could be increasing the level of damage in this crop. In contrast, *Apanteles ruficrus* causes a 72.6% reduction in food consumption by *M. separata* (Hill 1986, 1988). It would probably cause a similar reduction in *Chrysodeixis eriosoma*, so where both parasitoids are present in similar proportions, the effects of one would to some extent offset the effect of the other.

Possible interactions between *Copidosoma floridanum* and trichogrammatid egg parasitoids have been briefly considered. R.A. Cumber (DSIR files) carried out preliminary laboratory experiments which suggested that neither parasitoid completely excluded the other. This work should be extended to define the relationship more precisely. Field records of trichogrammatid parasitism during and after the period of *C. floridanum* introduction have been discussed by Roberts (1986). These contrast the high rates of parasitism recorded in 1975 by R.A. Cumber (80-96% in Paihia and 85-100% in Auckland, DSIR files) compared with subsequent lower rates. In March 1976, R.L. Hill recorded an average of 54% parasitism (by trichogrammatids) of *Chrysodeixis eriosoma* eggs north of Whangarei (Entomology Division DSIR 1976), and 11% in Auckland and the Waikato (DSIR files). Between 1976 and 1979, Roberts (1982) collected and reared 556 *C. eriosoma* eggs in the Auckland region of which only six were parasitised by trichogrammatids, and observed no parasitism from a further 961 in the field at Mahurangi near Warkworth in 1980/81. The surveys by R.A. Cumber and R.L. Hill, also showed that parasitism rates in *C. eriosoma* were similar to those in *Helicoverpa armigera* (Hübner). P.J. Cameron (unpublished) has also shown that low rates of trichogrammatid parasitism of *C. eriosoma* are not accompanied by increases in *Copidosoma floridanum*. This suggests that trichogrammatid parasitism varies greatly between sites and is not clearly affected by *C. floridanum*. More laboratory and field studies are required to determine if any interactions exist.

Apanteles ruficrus

Considerable variation in rates of parasitism of *Chrysodeixis eriosoma* by *A. ruficrus* have been recorded. In a larval survey in 1975-76, Hill *et al.* (1985) found *A. ruficrus* parasitising 7-10% of all *C. eriosoma* larvae, with 40% parasitism in one maize field where *M. separata* was abundant. This suggests that the high parasitism rate of *C. eriosoma* in maize may be attributable to the abundance of *A. ruficrus* parasitising *M. separata* (see Chapter 19). *A. ruficrus* was much less abundant in a survey of *C. eriosoma* parasitoids conducted 1976-82, mostly in Auckland gardens (Roberts 1982). Of approximately 2,000 *C. eriosoma* larvae collected from a variety of plants and successfully reared to produce either adult moths or parasitoids, *A. ruficrus* was recorded on only four occasions, i.e. 0.2% parasitism. More recently, parasitism rates of 21-27% (P.J. Cameron unpublished) and 29% (Hill *et al.* 1987) have been recorded on soybeans. Both these studies were conducted in South Auckland cropping areas.

Conclusions

Pronounced increases in food consumption are generally associated with gregarious and/or egg-larval parasitoids such as *Copidosoma floridanum* (Roberts 1982). Three polyembryonic species have been examined for their effect on host food consumption; *Copidosoma bakeri* (Howard) by McMillan (1930); *Paraleurocerus bicoloripes* Girault by Fizgerald & Simeone (1971); and *C. floridanum* by Hunter & Stoner (1975), Jones *et al.* (1982) and Roberts (1982). In each case a considerable increase in food consumption was recorded, the greatest increase being caused by *C. floridanum* parasitising *Chrysodeixis eriosoma*. These results suggest that the use of polyembryonic parasitoids which increase host feeding should be approached with considerable caution in biological control.

As there were no estimates of *C. eriosoma* damage or population density prior to the release of *Copidosoma floridanum* it is not possible to determine if significant changes have occurred. Although high levels of parasitism have been recorded, the greatest impact of *C. floridanum* on *Chrysodeixis eriosoma* populations is delayed to midsummer by poor synchronisation with its host in the late winter/early spring period. The parasitoid also prolongs the life of the most damaging stage and increases its food consumption significantly. Assessment of the relative impact of *Copidosoma floridanum* on population trends of *Chrysodeixis eriosoma*, compared with its detrimental effects on feeding damage, would require comprehensive life table studies. Ideally these should compare stable habitats where the *Copidosoma floridanum* is common, with commercial crops where rates of parasitism are lower. At present it is unclear whether the importation of *C. floridanum* was beneficial.

The need for further biological control introductions against *Chrysodeixis eriosoma* is complicated by the arrival in New Zealand of *Thysanoplusia orichalcea* which augments noctuid defoliation on several crops. Future consideration could be given to the introduction of *Trichogramma* spp. for these and other noctuids, as discussed in Chapter 21. Any introductions should be preceded by studies of the host relationships of the existing parasitoid species. The effects of *A. ruficrus* on both noctuids is currently being assessed (P.J. Cameron unpublished) and no further introductions of larval or pupal parasitoids are currently proposed.

Acknowledgements

We acknowledge use of the unpublished records of R.A. Cumber, R.L. Hill and D.J. Allan. M.G. Hill commented on drafts of this review.

Literature Cited

Allan, D.J. (1987) Flight records of four common pest noctuids (Lepidoptera: Noctuidae) in West Auckland 1978-1979. *New Zealand entomologist* 10, 122-127.

Bouček, Z. (1988) Australasian Chalcidoidea (Hymenoptera). CAB International, Wallingford, U.K., 832 pp.

Cameron, P.J.; Allan, D.J.; Walker, G.P. (1986) Insect pests and crop damage in soybeans. *New Zealand journal of agricultural research* 29, 93-100.

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242, 51 pp.

Cumber, R.A.; Allan, D.J.; Helmore, L. (1977) Introduction and successful establishment in New Zealand of further strains of *Apanteles ruficrus* Haliday (Hymenoptera: Braconidae) to combat *Pseudaletia separata* (Walk.) (Lepidoptera: Noctuidae). *New Zealand journal of agricultural research* 20, 255-258.

Dufay, C. (1973) Les Plusiinae des expéditions allemandes au Népal de 1955 à 1976 (Lepidoptera, Noctuidae). *Khumbu Himal* 4, 389-400.

Dugdale, J.S. (1968) A note: some records of Australian Noctuidae in New Zealand. *New Zealand entomologist* 4, 13-14.

Dugdale, J.S. (1972) A note on the Kermadec Islands Lepidoptera. *New Zealand entomologist* 5, 197-203.

Entomology Division DSIR (1976) Annual report 1976.

Fitton, M.G.; Gauld, I.D.; Roberts, L.I.N.; Walker, A.K. (1983) An African ichneumonid (Hymenoptera) in Australasia. *Bulletin of entomological research* 73, 465-468.

Fitzgerald, T.D.; Simeone, J.B. (1971) Polyembryony in *Paraleurocerus bicoloripes* (Hymenoptera: Encyrtidae). *Annals of the Entomological Society of America* 64, 774-777.

Fox, K.J. (1970) More records of migrant Lepidoptera in Taranaki and the South Island. *New Zealand entomologist* 4, 63-66.

Fox, K.J. (1972) Migrant Lepidoptera in New Zealand 1971-1972. *New Zealand entomologist* 5, 143-146.

Fox, K.J. (1978) The transoceanic migration of Lepidoptera to New Zealand – a history and a hypothesis on colonization. *New Zealand entomologist* 6, 199-200.

Gaskin, D.E. (1966) Butterflies and common moths of New Zealand. Whitcombe and Tombs Ltd, Christchurch. 219 pp.

Gaskin, D.E. (1970) Analysis of light trap catches of Lepidoptera from Palmerston North, New Zealand in 1966-68. *New Zealand journal of science* 13, 482-499.

Hill, M.G. (1986) Effects of *Cotesia ruficrus* (Braconidae: Hymenoptera) parasitism and rearing density on *Mythimna separata* (Noctuidae: Lepidoptera) food consumption, and implications for biological control. *New Zealand journal of agricultural research* 29, 281-288.

Hill, M.G. (1988) Analysis of the biological control of *Mythimna separata* (Lepidoptera: Noctuidae) by *Apanteles ruficrus* (Braconidae: Hymenoptera) in New Zealand. *Journal of applied entomology* 25, 197-208.

Hill, R.L.; Cumber, R.A.; Allan, D.J. (1985) Parasitoids introduced to attack larvae of the Noctuidae (Lepidoptera) and their establishment in New Zealand 1968-78. Entomology Division Report no. 5, 24 pp.

Hill, M.G.; Cameron, P.J.; Dugdale, J.S.; Allan, D.J.; Walker, G.P. (1987) Biology of *Thysanoplusia orichalcea* (Lepidoptera: Noctuidae) in New Zealand. *New Zealand entomologist* 10, 44-50.

Hudson, G.V. (1898) New Zealand moths and butterflies. West, Newman and Co. Ltd, London. 144 pp.

Hunter, K.W.; Stoner, A. (1975) *Copidosoma truncatellum*: effect of parasitization on food consumption of larval *Trichoplusia ni*. *Environmental entomology* 4, 381-382.

Jones, D; Jones, G.; van Steenwyk, R.A.; Hammock, B.D. (1982) Effect of the parasite *Copidosoma truncatellum* on development of its host *Trichoplusia ni*. *Annals of the entomological society of America* 75, 7-11.

Kostrowicki, A.S. (1961) Studies on the Palaearctic species of the subfamily Plusiinae (Lepidoptera, Phalaenidae). *Acta Cracoviensia* 6, 367-472.

McMillan, E. (1930) A preliminary study of the polyembryonic cutworm parasite *Berecyntus bakeri* var. *gemma* Girault. M.Sc. thesis, University of Saskatchewan.

Noyes, J. (1988) Encyrtidae (Insecta: Hymenoptera). *Fauna of New Zealand* 13, 188 pp.

Roberts, L.I.N. (1979) Biology of *Chrysodeixis eriosoma* (Lepidoptera: Noctuidae) in New Zealand. *New Zealand entomologist* 7, 52-58.

Roberts, L.I.N. (1982) Inter-relationships between the polyembryonic parasitoid *Litomastix maculata* (Hymenoptera: Encyrtidae) and its host the green looper caterpillar *Chrysodeixis eriosoma* (Lepidoptera: Noctuidae). Ph.D. thesis, Auckland University, New Zealand. 134 pp.

Roberts, L.I.N. (1986) The practice of biological control – implications for conservation, science and the community. *The weta* 9(2), 76-84.

Spitzer, K. (1970) Observations on adult activity of Noctuidae (Lepidoptera) during winter in the Manuwatu, New Zealand. *New Zealand journal of science* 13, 185-190.

Stoner, A.; Weeks, R.E. (1976) *Copidosoma truncatellum*, a polyembryonic parasite of *Trichoplusia ni*: age of host eggs parasitised, searching, fecundity and effectiveness. *Environmental entomology* 5, 323-328.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Valentine, E.W. (1975) Current projects on biological control of insects. *Proceedings of the 28th New Zealand Weed and Pest Control Conference*, 193-195.

Watt, M.N. (1915) Contributions to the study of New Zealand entomology from an economical and biological standpoint: No. 1 – *Plusia chalcites* Esp.; No. 2 *Nyctemera annulata* Boisd.; No. 3 – *Venusia verriculata* Feld. Lepidoptera. *Transactions and Proceedings of the New Zealand Institute* 47, 245-274.

Coleophora frischella L., whitetipped clover casebearer, *C. spissicornis* Haworth, banded clover casebearer (Lepidoptera: Coleophoridae)

W.D. PEARSON

Pest Status

White clover, *Trifolium repens* L., the primary host of both *Coleophora frischella* L. and *C. spissicornis* Haworth, was distributed throughout New Zealand soon after European settlement (Hooker 1864). *T. hybridum* L., *T. pratense* L., *T. fragiferum* L. and *T. arvense* L. are occasional hosts. The first records of *C. spissicornis* in this country were from Banks Peninsula (Lindsay 1927) and Whangarei (Patterson 1930), which are widely separated localities. Hamilton (1944) recorded the flight period as '...from November until March, being plentiful during January and February', a description which fits a mixed population of the univoltine *C. spissicornis* and the multivoltine *C. frischella*. The latter was not recognized as a separate species until 1955 (Dumbleton 1959). Both species were probably imported in hay accompanying livestock.

Mature larvae overwinter in their cases and pupate in the spring. Moths of both species oviposit in open white clover flowers and larvae feed only on developing seed during the 22-23 days after floret pollination. Prior to the third moult, larvae are completely enclosed within seed pods. Larvae then construct a case from which they feed, pulling it in among the withered flowers of the infloreseence. *C. spissicornis* larvae complete feeding approximately 25 days after eclosion. Similarly, *C. frischella* larvae that are destined to enter diapause complete development in 25 days, but those which pupate to form a second or third generation take only 15 days. These larvae attach the case in the inflorescence and pupate immediately. Those which will overwinter, and all *C. spissicornis* larvae, descend to the ground in their cases and enter diapause but may become active during warm periods.

Flowering in white clover seed crops generally peaks around mid-December, and harvesting is in late January. The *Coleophora* spp. flight period is well synchronized with the crop in Canterbury (Dumbleton 1963, Pearson 1975). *C. frischella* moths are also present in January and February but have little impact on crop yields. Casebearer was recognized as a problem in 1940 (Hamilton 1944). Kelsey (1958) and Dumbleton (1963) found that yield reductions of from 3% to 84% were attributable to these pests. In seasons of high clover casebearer populations yields were so reduced that some crops were not harvested (DSIR files). Losses were generally reduced with the introduction of rotational cropping systems in which white clover is only harvested for a single year. Chemical control methods became available in 1960 (Dumbleton 1959, Hoy 1960). Non-residual insecticides which could be applied to the crop in the evening to avoid damage to essential pollinators became available soon afterwards (Dumbleton 1964).

Background

When the biological control programme began, the identification of casebearers both in Europe and in New Zealand was confused. In 1950 Dumbleton (1952) recognized *C. spissicornis* and a second species, which was identified as *C. frischella* on the basis of erroneously labelled genitalia in figures by Pierce & Metcalfe (1935), DSIR files, Bradley (1967). How-

ever, in Europe, the name *C. frischella* was then applied to *C. trifolii* (Curtis), while the true *C. frischella* was known as *C. alcyonipennella* (Kollar). The application of these names and the dates of the changes, based on Bradley (1967), are documented in Table 13.1. The use of these names is further discussed by Dugdale (1988).

Table 13.1 Application of *Coleophora* species names in New Zealand, Australia and Europe on two host plants, indicating changes over time. Based on Bradley (1967).

Year	New Zealand	Australia	Europe	
	T. repens	*T. repens*	*T. repens*	*Melilotus* sp.
1950	*frischella*	*deauratella*	*alcyonipennella*	*frischella*
1952	*frischella*	*frischella*	*alcyonipennella*	*frischella*
1956	*alcyonipennella*	*alcyonipennella*	*alcyonipennella*	*frischella*
1967	*frischella*	*frischella*	*frischella*	*trifolii*

C. spissicornis is found from France (Verbeke 1957) north to Finland (Benander 1939, Hackman 1945) and is common in England (Chalmers-Hunt 1975). *C. frischella* is rare in England (Chalmers-Hunt 1975) and Zwölfer (1968) found it was limited to the Bay of Biscay, the Mediterranean coasts of France and northern Italy and southern Switzerland. However Jalava (1977) records it from southern Finland and adjacent Russia at 63° north. These museum records indicate a multivoltine species, uncommon among the Coleophoridae.

Very little has been published on mortality factors affecting either species in New Zealand. Dumbleton (1952) reported three out of 20 overwintering *Coleophora* spp. larvae attacked by a nematode, *Neoaplectana* sp., at Blenheim. Pearson (1975) found *Coleophora* spp. near Christchurch attacked by *Pyemotes* sp. (not *P. zwoelferi* Krkcal, (R. Emberson pers. comm.)). In occupied cases collected in late January and February, four of 1,532 and one of 366 larvae were attacked. Thomas (1969) also found *Coleophora* spp. larvae attacked by *Pyemotes* sp. near Nelson. Moths are preyed upon by *Nabis capsiformis* Germar (Pearson unpublished).

Pearson (1975) examined the contents of 6,066 clover casebearer cases extracted from litter samples from an area of undisturbed white clover. In about 8% of occupied cases (316 of 3,760) the larvae had been killed by the fungi *Fusarium* sp., *Hymenostilbe* sp., *Beauveria bassiana* (Balsamo) Vuillemin, *Paecilomyces* sp. and *P. ?fumoso-roseus* A.H.S. Drown & G. Smith (Wize) (I. Harvey pers. comm.).

In 1965 Zwölfer (DSIR files) found a new microsporidian species in a European population of *C. alcyonipennella* (later renamed *C. frischella* and generally referred to as *C. frischella* hereafter). Field collected larvae sent from New Zealand to Europe were also found to be infected. The disease is not always fatal. Pearson (1975) found an unknown factor, possibly the microsporidian, which left completely collapsed cadavers extended along the side of the case in 17% of *Coleophora* spp. cases examined.

In the same area the population declined by 40% over the autumn-winter period, March to October. In addition to the above factors, worms and starlings, *Sturnus vulgaris* L., contribute to this loss. Lobb & Wood (1971) found residues of clover casebearer larvae in starling faeces in every month but August. Residues were most prevalent from January to April, the period when diapausing larvae were most active. Larvae in cases also become trapped under worm castings deposited on the surface over the winter (Pearson unpublished).

Overwintering larval populations may be reduced significantly by cultural practices. After harvest of a white clover seed crop, Pearson (1975) found that one cultivation method which buried surface trash led to a decline in casebearer numbers from 450 m^{-2} on the soil surface in April to only 11 larvae m^{-2} in a position from which they could emerge in October. This

represents a survival rate of 2.4% in the top 1 cm and it is unlikely that adults could emerge from any cases that were completely buried.

Importations, Releases and Recoveries

New Zealand first requested parasitoids of clover casebearers for *C. spissicornis* control from the CIBC in 1948 (DSIR files). Following Dumbleton's discovery of *C. frischella* in New Zealand, and since this species was more readily found in Europe than was *C. spissicornis*, the search was concentrated on parasitoids of the former species (Stuart 1958, Verbeke 1952). However, *C. frischella* sensu Dumbleton was probably *C. paripennella* Zeller, while the European species known as *C. frischella* was actually *C. trifolii* (see Table 13.1). No specimens were exchanged and the error remained undetected until 1955.

Importation of parasitoids for biological control of clover casebearers continued from 1952 to 1969, a period which can be considered in two phases before and after 1955 when agreement was reached on the identity of *C. frischella* in New Zealand and Europe. *C. trifolii* larvae were imported in 1952 and 1955, and parasitoids were reared and released in 1952. After this agreement, from 1961 to 1969, both *C. frischella* and *C. deauratella* Lienig & Zeller were imported. *C. deauratella* was imported because it was thought that it could serve as a source of parasitoids. It is closely related to *C. frischella* and they have similar habitats and hosts. *C. deauratella* larvae overwinter in cases attached to tree trunks and are more easily gathered than those of *C. frischella*.

With two exceptions, all parasitoids were imported as collections of encased, fully-fed, fourth instar larvae. Parasitism rates were determined from samples of cases dissected before shipment (Table 13.2). Encased larvae and parasitoids were gathered by staff of the European Station of CIBC and the same localities were used for successive collections. *C. trifolii* larvae were collected from *Melilotus altissima* Thuillier in Belgian Luxembourg and Montmédy in northern France. *C. deauratella* larvae, imported in 1961 and 1969, were collected from orchards near Freiburg in southern Germany. For parasitoids of *C. frischella* white clover flower heads were collected in late August and early September from the area around Avignon in southern France. Larvae were reared at Delémont, Switzerland, and encased *C. frischella* were sent to New Zealand in 1961, 1962, 1967, 1968 and 1969 (Table 13.2).

No specific efforts have been made to determine whether or not any of the parasitoids released have established.

Agathis rufipalpis Nees or *Agathis* sp. (Hymenoptera: Braconidae)

Information about these parasitoids has been obtained from Zwölfer (1961a, 1961b) and a letter from H. Zwölfer to E.W. Valentine in 1969 (DSIR files). This parasitoid attacks *C. frischella*, *C. deauratella* and possibly *C. spissicornis* but there is some question as to its identity. *Agathis* sp. larvae found in the three *Coleophora* spp. are morphologically identical, as are adults reared from *C. frischella* on white clover and *C. deauratella* on red clover (Zwölfer 1961a). No adult parasitoids have been obtained from *C. spissicornis*. The species obtained from *C. frischella* and *C. deauratella* was later determined by O. Fischer as *A. rufipalpis* (DSIR files). *A. rufipalpis* males reared from *C. frischella* on white clover from southern France mated readily with females reared from *C. deauratella* on red clover from Germany. However, the population appeared to consist of genetically isolated ecotypes since adults reared from *C. deauratella* cases imported to New Zealand failed to parasitise *C. frischella* here.

A. rufipalpis is well synchronised with its host. The adult searches flower heads and oviposits into first and sometimes second instar larvae. Eclosion occurs about a week later

Table 13.2 Encased *Coleophora* spp. larvae imported as parasitised hosts. *C. deauratella* collected near Freiburg, *C. frischella* near Avignon and *C. trifolii* near Montmédy

Host species	Year	Number	Parasitism rate (%)	Pre-shipment storage conditions
C. deauratella	1961	3,670	30–40	Cold; 0-4°C for 70 days
C. deauratella	1969	4,500	24	Cool; 7°C 55 days (pre and post shipment)
C. frischella	1961	6,237	6– 9	Cold; 0-4°C for 100 days
C. frischella	1961	760	?	Cold; 0-4°C for 75 days
C. frischella	1962	4,500	21	Cold; 0-4°C for 70 days
C. frischella	1967	2,350	1– 2	Warm, short day; 15-18°C for 28 days then 12°C for 105 days
C. frischella	1968	3,470	5–10	Unheated glasshouse 75 days then 1-4°C for 0, 10 and 20 days
C. frischella	1969	1,400	13	Cool; 7°C 55 days (pre and post shipment)
C. trifolii	1952	9,000	66	Shipped directly
C. trifolii	1955	5,000	?	Shipped directly

but development is arrested until the host prepares to pupate, so that adult wasps emerge when new hosts are available. Because of its close synchrony with the host, *A. rufipalpis* was considered to be the the most desirable parasitoid and repeated efforts were made to introduce it (Table 13.3).

The 1961 shipment contained an estimated 360 to 490 *A. rufipalpis* in the *C. frischella*, of which one male and two females emerged and were preserved as reference specimens. There were no *A. rufipalpis* emergences from the *C. deauratella* cases. An outbreak of the mite *Pyemotes zwoelferi* Krczal forced the destruction of all material under quarantine on 2 February 1962.

The 1962 shipment contained an estimated 335 to 730 *A. rufipalpis*. In New Zealand another outbreak of *P. zwoelferi* forced destruction of all material shortly after emergences started. Three female wasps had emerged and were liberated near Nelson.

In early February 1966, 17 female and 47 male wasps were shipped to New Zealand and those remaining alive (16 females and 42 males) were liberated directly into a *Coleophora* spp. infested white clover area at the Nelson laboratory. The area contained flowering white clover (DSIR files) but the date suggests there may have been few hosts of a suitable age available.

Parasitised larvae collected in 1967 (Table 13.2) were shipped to New Zealand in January, 1968. It was intended to use emerging *A. rufipalpis* to establish a rearing colony in the laboratory. Only one female and two males emerged and although mating was achieved no oviposition occurred in *Coleophora* spp. and rearing failed (DSIR files). The 1968 collection was divided into three shipments which arrived in October (1,270 cases), November (1,100) and December (1,200). Emerging adults were also intended for the establishment of a laboratory rearing colony but only three individuals emerged in transit and no releases were made (DSIR files).

The *C. frischella* larvae collected in Europe in 1969 (Table 13.2) were estimated to contain 28 *A. rufipalpis* and the *C. deauratella* larvae an estimated 360 individuals. 'Small numbers' were released in the field (DSIR files).

There have been no recoveries of *A. rufipalpis*.

Apanteles sp. (Hymenoptera: Braconidae)

A single *Apanteles* sp. wasp was among the parasitoids which emerged from the 5,000 *C. trifolii* cases imported in 1955 and were sent to the Commonwealth Institute of Entomology (CIE) for identification. It is now deposited in the New Zealand Arthropod Collection. No parasitoids from this shipment were released (Stuart 1958).

Table 13.3 Parasitoid species included in New Zealand importations for the control of *Coleophora* spp. on white clover, 1952 to 1969.
*indicates species established

Parasitoid species	Years of importation	Estimated number imported	Estimated number liberated	Reference
BRACONIDAE				
Agathis rufipalpis	61 62 68 69	1,536	0, 3, 0, ?	DSIR files
Agathis rufipalpis	61 69	360+	0, ?	Thomas 1969
Agathis sp.	66	64	58	DSIR files
Bracon osculator	52 55	?	100+, 0	Stuart 1958
**Bracon variegator*	61 62 68 69	1,075+	155+, 15, ?, ?	Thomas 1969
?*Chelonus* sp.	61 68	17+	0, 0	Thomas 1969, DSIR files
Chelonus contractus	61 69	270+	0, small no.	DSIR files
EULOPHIDAE				
**Chrysonotomyia trifolii*	61 62 67 68 69	1,944+	0, 0, 0, 1,600, ?	Entomology Div. 1977
EURYTOMIDAE				
Eurytoma sp.	61	3,670	0	Thomas 1969
ICHNEUMONIDAE				
Diadegma sp.	55	?	0	Stuart 1958
Diadegma majalis	52	?	?	Cawthron Inst. 1953
Diadegma majalis	68	?	0	DSIR files
Casinaria (= *Horogenes*) sp.	62	70	0	DSIR files
Casinaria (= *Horogenes*) sp.	69	450	?	DSIR files
Scambus brevicornis	52 55	?	?, 0	DSIR files
Gelis tonsus	55	?	0	Stuart 1958
Gelis areator	55	?	0	DSIR files
Gelis sp. ?*areator*	55	?	0	DSIR files
Itoplectis maculator	55	?	0	DSIR files
Pristomerus orbitalis	52 55	?	?, 0	Stuart 1958
PERILAMPIDAE				
Perilampus sp.	61 69	65+	0, 0	Thomas 1969, DSIR files
PTEROMALIDAE				
Pteromalus semotus	52 55	?	several hundred, 0	Stuart 1958
PYEMOTIDAE				
Pyemotes zwoelferi	61 62 68 69	112+	0, 0, 0, 0	Thomas 1969, DSIR files

Bracon osculator Nees (Hymenoptera: Braconidae)

Verbeke (1957) gives a short account of the biology, morphology and parasitism rates of this parasitoid of *C. trifolii*, which was imported in 1952 and 1955 (Table 13.3). Approximately 100 adult wasps emerged from the material imported in 1952 and were liberated near Nelson in late December 1952 (1953?) (DSIR files) at a time when suitable hosts would have been available in the field. A further several hundred cases containing parasitised larvae were set in the field in March, 1953; some of these would have contained *B. osculator* (DSIR files). The 1955 importation of 5,000 encased, parasitised *C. trifolii* also contained some *B. osculator*. The five females and two males which emerged were destroyed after attempts to have them parasitise New Zealand casebearers failed. After examining a limited number of specimens, R.D. Eady (CIE) doubted that the species imported in 1955 was in fact *B. osculator* (DSIR files). There have been no recoveries of *B. osculator*.

Bracon variegator Spinola (Hymenoptera: Braconidae)

The biology of *B. variegator* and details of laboratory and greenhouse breeding methods are discussed by Thomas (1969). These parasitoids were imported in 1961, 1962, 1968 and 1969. A breeding colony, established from *B. variegator* which emerged from the material imported in 1961, before the *P. zwoelferi* outbreak, resulted in the production of 57 females and 98 males which were liberated in the grounds of the Cawthron Institute at Nelson. Ten white clover plants, each infested with more than 100 *Coleophora* spp. larvae, an unknown number of which were parasitised by *B. variegator*, were also planted into infested white clover areas; four at Wakapuaka, near Nelson, and six at Entomology Division, Nelson (Thomas 1969, DSIR files). The material imported in the 1962 shipment (Table 13.2) produced a further six female and nine male *B. variegator* which were liberated at Nelson (DSIR files). This shipment was also destroyed after an infestation of *P. zwoelferi* was discovered.

In 1968 a total of 3,570 encased *C. frischella* larvae was received in three consignments during October, November and December. The intent of these shipments was to establish breeding colonies of other parasitoids, *Agathis rufipalpis* and *Chrysonotomyia trifolii*, and for direct field release if numbers were sufficient (DSIR files). There is no record of *B. variegator* emergence from these larvae but Zwölfer (DSIR files) indicated that this species was present in the shipments. The last shipment, in 1969, contained an estimated 70 *B. variegator*. The intent of this shipment was to establish breeding colonies of other parasitoids and for field release. There is no record of *B. variegator* emergence from these larvae either.

Although there is no record of emergences or releases from either of these last two shipments, a list of releases compiled by E.W. Valentine (DSIR files) and covering the period 1966 to 1970 includes *B. variegator*. The 1968 and 1969 shipments are the only ones from which these releases could have been made.

Establishment was confirmed in March 1966 by B.B. Given when *B. variegator* emerged from *Coleophora frischella* larvae he had collected in the field at Nelson (Thomas 1969, DSIR files). *B. variegator* adults were subsequently collected in the Nelson area and released at Lincoln, 280 km to the south, 10 pairs in 1967 and 2,450 individuals, including 1,015 females, in 1968. Fifty pairs were also liberated at Cheviot, 180 km to the south, in 1968 (DSIR files). Establishment at Lincoln was determined by collection of one parasitised larva among 400 collected 800 m from the release site in April 1970 (DSIR files). Two years later, at the same distance from the release site, in a quantitative study of the white clover casebearer population, Pearson (1975) found 1,125 fourth instar *Coleophora* spp. larvae/m^2, 29.6% of which were parasitised by *B. variegator*. *B. variegator* was also found to be established at Palmerston North in 1981 (DSIR files).

B. variegator was supplied to G. Snowball, Commonwealth Scientific and Industrial Research Organisation, Sydney, Australia in 1969. It is not known if it has established in Australia (W.P. Thomas pers. comm.).

Chelonus sp. and *Chelonus contractus* Nees (Hymenoptera: Braconidae)

It is probable that the parasitoids imported under these names are the same. *Chelonus* sp. is a primary parasitoid which in Europe is most numerous in the univoltine *Coleophora deauratella*. There is a *Chelonus* sp. very commonly found in the univoltine *Coleophora spissicornis* which have larvae identical to that from *C. deauratella* but no adults have been obtained so verification of the identity has not been possible. However, adults identical to those obtained from *C. deauratella* were obtained from *C. frischella*. It occurred only rarely in *C. frischella* (Zwölfer 1961b).

Chelonus sp. are egg-larval parasitoids. The adult wasp searches clover flower heads for *Coleophora* sp. eggs, preferring newly deposited eggs for oviposition (Zwölfer 1961b). The *Chelonus* sp. larva emerges after a few days and enters the *Coleophora* sp. embryo within its egg. The parasitoid larva remains in the first instar until the host prepares to pupate, then develops rapidly so that the adult wasps emerge at about the same time as the *Coleophora* sp. adults, ensuring a ready supply of hosts.

This parasitoid was imported in 1961, 1968 and 1969. In the 1961 shipments Zwölfer (1961c) estimated there were nearly 1,000 *Chelonus* sp. nr *contractus* larvae among the *Coleophora deauratella* larvae and another eight to 10 among the *C. frischella* larvae. None emerged before all the material was destroyed because of the *P. zwoelferi* outbreak. Material in the 1968 shipment contained 'some Cheloninae' (DSIR files) but only three females emerged and there is no record of their fate. In the *C. deauratella* shipments of 1969, received in October and December, there were an estimated 270 *Chelonus contractus*. 'Small numbers' emerged and were released (DSIR files). There have been no recoveries of *Chelonus* sp.

Chrysonotomyia (= *Neochrysocharis*) *trifolii* (Erdös) (Hymenoptera: Eulophidae)

The adult of this internal parasitoid oviposits into second and third instar *Coleophora* spp. larvae feeding in inflorescences. Both *C. frischella* and *C. deauratella* are attacked (Zwölfer, 1961a). The host is not killed until after it completes its feeding and enters the migratory phase on the ground. Fully developed larvae overwinter inside the host's distended integument, forming a mummy inside the host's case. Zwölfer found that eight to 14 or more *Chrysonotomyia trifolii* adults emerged from a single mummy (DSIR files) but in New Zealand 17 commonly emerged (Pearson unpublished).

C. trifolii was imported in 1961, 1962, 1967, 1968 and 1969 under the name *Neochrysocharis* sp. This parasitoid was not considered to be the most desirable for introduction because its synchronization with the host was thought to be less precise than others, such as *A. rufipalpis*, to which it is superior in competition (Zwölfer 1962). No effort was made to release it until 1967.

C. trifolii wasps which emerged from the *Coleophora frischella* material imported in 1961 were preserved as reference specimens. There was no estimate of the parasitism rate in this shipment. The 1962 shipment contained an estimated 70 *Chrysonotomyia trifolii* mummies. Wasps which emerged were left in the tubes to die (DSIR files). Emergences from both these shipments were halted by outbreaks of *P. zwoelferi*.

The 1967 shipment included a collection of 25 *C. trifolii* mummies, which Zwölfer (DSIR files) expected to produce 200 to 300 adult wasps. These were to be used to establish a laboratory culture. One male and 58 females emerged (DSIR files) and first generation progeny were obtained. It is not known whether or not these mated but the second New Zealand generation contained only males (DSIR files).

There was no estimate of the number of *C. trifolii* mummies included in the 1968 shipments (Table 13.2) but emerging wasps were used to establish a culture, employing field collected case bearing larvae as hosts. After three generations approximately 1,600 adults were liberated in the Manawatu at Palmerston North, an area where it was thought that *B. variegator* had not yet established (DSIR files).

Zwölfer (DSIR files) expected the 1969 shipment to contain about 100 *C. trifolii* mummies. Adults were intended for direct field release and for establishing a laboratory culture. The culture was established, using field collected case bearing larvae parasitised by an unstated number of *C. trifolii* wasps from the shipment and about 60 which emerged from the remnants of the previous seasons culture (DSIR files). Valentine intended that these wasps also be released in the North Island but the culture was an almost complete failure and neither the numbers released nor the release location are stated (DSIR files).

Establishment was confirmed in January 1977 when two *C. trifolii* mummies were found in a collection of 253 encased first generation *Coleophora frischella* at Lincoln (Entomology Division DSIR 1977), 450 km south of the release site. By the following generation, in mid-March, parasitism had increased to 49 mummies among 790 (6.2%) *C. frischella*. By the first generation of 1978 the rate had increased further to 532 mummies among 1911 (27.8%) encased larvae (Entomology Division DSIR 1978). A survey conducted in 1982 found *Chrysonotomyia trifolii* established throughout Canterbury and the Manawatu with parasitism rates of 49.7% and 10.3% respectively (DSIR files).

Eurytoma sp. (Hymenoptera: Eurytomidae)

These are parasitoids of *Coleophora deauratella* and other coleophorids which overwinter in cases attached to tree trunks. The parasitoids overwinter as mature larvae within host cases (Zwölfer 1961a). Nothing else is known of its biology. *Eurytoma* sp. was imported in the *C. deauratella* larvae imported in 1961. Eleven females and four males emerged but were still under quarantine when the *P. zwoelferi* outbreak occurred and they were destroyed (W.P. Thomas pers. comm.).

Diadegma majalis (Gravenhorst) (Hymenoptera: Ichneumonidae)

C. trifolii and *C. frischella* are hosts of this species. Verbeke (1957) gives notes on its biology, morphology and parasitism rates in Europe. The adult female oviposits into host larvae and eclosion occurs soon after. First instar larvae diapause over winter and resume development in early spring. In Europe, adults emerge from mid-April to early June and mating occurs soon after. Verbeke (1957) postulated an intermediary host to allow the parasitoid to complete its yearly cycle but Zwölfer (DSIR files) found the adults to be long lived.

D. majalis was imported in August 1952 and in 1968. There is no record of rates of parasitism by individual parasitoids in the 1952 importation of *C. trifolii* larvae but total parasitism was estimated at 60% to 70% (DSIR files). Encased larvae were held in cool storage until locally collected hosts became available (DSIR files). Emergence continued over the summer. J. Timlin (DSIR files) noted, 'liberated several hundred parasitised hosts' in March 1953, probably in Nelson. These parasitised hosts contained specifically *D. majalis* and *Pristomerus orbitalis* Holmgren. There is no record of emergences or recoveries from these liberations. *D. majalis* were also reared from the three 1968 importations of *C. frischella* larvae. Forty-three wasps emerged, 12 females and 31 males. These were presented with *Coleophora* spp. of various stages on insectary grown white clover plants. Oviposition was observed but no emergences occurred (DSIR files).

Diadegma sp. (Hymenoptera: Ichneumonidae)

Nothing is known of the biology of this species. Eight individuals were reared from the 5,000 encased *C. trifolii* larvae imported in the 1955 shipments. They were destroyed after attempts to have them parasitise New Zealand *Coleophora* spp. failed (Stuart 1958).

Casinaria (= *Horogenes*) sp. (Hymenoptera: Ichneumonidae)

Casinaria sp. adults search *Trifolium* spp. inflorescences and oviposit into early instar larvae of *Coleophora* spp. feeding in developing seeds. Synchronization with the hosts, *C. frischella* and *C. deauratella*, is not as well developed as that in *Agathis rufipalpis* or *Chelonus* sp. and adults often fail to emerge from *Coleophora deauratella* cases (DSIR files). Little else is known of the biology. Parasitism rates in the European collection areas in 1969 were 2% of *C. frischella* and 20% of *C. deauratella*.

A shipment of *C. frischella* larvae, received in November 1962, contained about 80 *Casinaria* sp. Three males emerged and were preserved for reference. An outbreak of *P. zwoelferi* forced the termination of further emergences before the end of that month.

The 1969 shipment of *Coleophora deauratella* larvae contained an estimated 450 *Casinaria* sp. (DSIR files). There is no record of the numbers that emerged. Two female and two male *Casinaria* sp. put into a cage with early instar *Coleophora* spp. infested white clover inflorescences showed no interest in the flowers (DSIR files). A 'small number of *Casinaria*' sp. parasitised encased host larvae were released at Appleby, near Nelson (DSIR files). There have been no recoveries.

Scambus (= *Ephialtes*) *brevicornis* (Gravenhorst) (Hymenoptera: Ichneumonidae)

S. brevicornis is an external parasitoid which has a wide range of lepidopterous hosts in Europe (Stuart 1957), and was imported to New Zealand among encased *Coleophora trifolii* larvae. Larval morphology and biology of *S. brevicornis* reared on *Plutella xylostella* (L.) is detailed by Stuart (1957) and Verbeke (1957) gives notes on the biology when the host is *C. trifolii*. In contrast to Stuart, Verbeke found that the adult wasp kills the host before oviposition and the developing larva then feeds upon the cadaver while it turns brown and liquefies.

S. brevicornis was included among the *C. trifolii* imported in August 1952. No hosts were available for emerging wasps and hibernating *Coleophora* spp. larvae were collected from the field for them (DSIR files). They were included in the unemerged material set out in the field in March 1953 but there is no record of numbers. *S. brevicornis* was also included among the *C. trifolii* imported in August 1955. Seven females and six males emerged (Stuart 1958). Subsequently, three females and five males were used to initiate a laboratory colony reared on *P. xylostella* (Stuart 1957). There were no releases from the 1955 shipment. No recoveries of *S. brevicornis* have been made.

Gelis tonsus Förster (Hymenoptera: Ichneumonidae)

This is a secondary parasitoid which was also included in the 1955 importation of *C. trifolii* larvae. One female emerged, and was sent to the BMNH for identification, and was retained there (DSIR files).

Gelis (= *Hemiteles*) *areator* (Panzer) and *G.* sp. ?*areator* (Panzer)(Hymenoptera: Ichneumonidae)

These species are also secondary parasitoids which emerged from the material imported in 1955. Specimens were sent to the BMNH for identification but the numbers are unknown (DSIR files). None were liberated (Stuart 1958).

Itoplectis maculator (F.) (Hymenoptera: Ichneumonidae)

This species is a primary pupal parasitoid of *Choristoneura murinana* (Hübner) (Zwölfer 1961d) and is also hyperparasitic in *Coleophora trifolii*. An unknown number emerged from the material imported in 1955 and were sent to the BMNH for identification (DSIR files). None were liberated (Stuart 1958).

Pristomerus orbitalis Holmgren (Hymenoptera: Ichneumonidae)

This species is a primary internal parasitoid of *C. trifolii*. The developing parasitoid larva overwinters as a first instar larva on the host's fat body. In Europe development resumes during May and adult wasps emerge around the beginning of July (Verbeke 1957). There is a close synchrony between parasitoid and host.

An unknown number of *P. orbitalis* were imported in 1952 and 1955. No releases of reared adult wasps were made from the 1952 importations (Stuart 1958) but several hundred parasitised hosts, containing *P. orbitalis* among other species, were set out in the field in March, 1953 (Cawthron Institute 1953, DSIR files). Some emerging adults from the 1955 shipment were used to test the ability of parasitoids to attack New Zealand *Coleophora* spp. and others were sent to the BMNH for identification. None were released from the 1955 shipment (DSIR files, Stuart 1958). There have been no recoveries of *P. orbitalis*.

Pteromalus semotus (Walker) (= *Habrocytus milleri* Delucchi & Verbeke) (Hymenoptera: Pteromalidae)

P. semotus is an ectoparasitoid of *C. trifolii*. It is a primary parasitoid but has also been found parasitising *B. osculator*, another ectoparasitoid of *C. trifolii*. The wasp stings and kills a host larva then deposits up to three eggs near the cadaver. The first hatched larva generally kills the remaining eggs and then develops on the decaying cadaver. More females than males are produced (Verbeke 1957).

P. semotus was imported in August 1952 and possibly in August 1955. When the first consignment of the 1952 shipment arrived 116 females and 183 males had emerged but there were no hosts available for them (DSIR files). Unemerged material was held in cool storage until *Coleophora* spp. larvae became available in the field. Considerable numbers emerged. Several hundred adults were released near Nelson in late December 1953 (?1952) and another 200 at Hastings (DSIR files). There have been no recoveries of *P. semotus*.

'*P. semotus*' was also included in the 1955 shipment, but a greater understanding of its biology led to its rejection as a possible biocontrol agent (DSIR files) even before the inconsistency in '*C. frischella*' identification was discovered (DSIR files). There is some question about the identity of the species. G.J. Kerrich of the BMNH was of the opinion that it did not agree with Delucchi & Verbeke's (1954) description of *P. semotus* and identified it as *H.* sp. ?*eucerus* Ratzeburg (DSIR files). Seven females and two males emerged and were sent to the CIE for identification (DSIR files) after laboratory trials to have them attack New Zealand *Coleophora* spp. failed (Stuart 1958). None were released.

Perilampus sp. (Hymenoptera: Perilampidae)

There is no information on the biology of this species, a hyperparasitoid which attacks the *C. deauratella* parasitoids *Agathis rufipalpis* and *Chelonus contractus*. It was imported in 1961 and 1969. No information is available on the 1961 importation. Zwölfer (DSIR files) estimated the 4,500 encased *Coleophora deauratella* larvae contained about 800 susceptible *A. rufipalpis* and *Chelonus contractus*, a part of which was parasitised by *Perilampus* sp. None were released.

Pyemotes zwoelferi Krczal (Acarina: Pyemotidae)

Newly born larvae are tiny and very active crawlers, penetrating *Coleophora* spp. cases through small fissures (Zwölfer 1961a). They attach themselves to the host by their mouthparts and feed externally, injecting a toxin which kills the host within a couple of days. Feeding is completed after about six days when the volume of the mite's abdomen has increased by about 3,200 fold. The first of several hundred offspring are produced about 15 days later and immediately begin searching for new hosts. Tightly constructed and closed *Coleophora* spp. cases are an adequate defence against *P. zwoelferi* and its use as a biocontrol

agent was rejected because of its wide host range and the probability of a detrimental effect on other existing host-parasitoid relationships (e.g. Taylor 1937).

In French white clover seed crops where *C. frischella* populations were high, Zwölfer (DSIR files) found that 30 to 40% of larvae had been killed by *P. zwoelferi*. However, on road verges, where the clover did not mature seed regularly and the *C. frischella* population was more sporadic, only about 7% of larvae were affected.

P. zwoelferi is known to have been imported in 1961, 1962, 1967 and 1969. It was probably also present in the 1968 shipment but records are missing. There were no living *P. zwoelferi* found in extensive samples examined from the material collected for the 1961 or 1962 shipments (DSIR files, Zwölfer 1962) but material of both shipments had to be destroyed as the result of outbreaks which occurred about 40 to 50 days after arrival (Thomas 1969). The material imported in 1962 had been held in cold storage (Table 13.2) before samples were taken. In a sample from a similar lot of material which had not been subjected to cold storage, 3.4% of the *Coleophora* spp. cases were found to contain *P. zwoelferi* (DSIR files). *P. zwoelferi* was known to have been included among the material imported in 1967 and 1969 (DSIR files) but no major outbreaks occurred. Pre-shipment conditions were quite different for the 1967 shipment than for other shipments (Table 13.2). The material imported in 1969 was shipped and reared in a large number of small glass tubes (DSIR files).

Evaluation

Emergence of parasitoids from the 18,800 *C. frischella* cases imported between 1961 and 1969 was disappointingly low. A part of this low production can be attributed to the presence of the predaceous mite *P. zwoelferi* which forced a premature halt to rearing on two occasions when emergences were progressing well (W.P. Thomas pers. comm.). Zwölfer (1961b, DSIR files) stressed the need for natural light exposure during incubation to promote emergence of closely synchronized parasitoids from *C. deauratella* cases but this requirement was incompatible both with shipment methods and with the secure nature of the quarantine facilities. A mercury vapour light was introduced into the quarantine area to enrich the spectrum (W.P. Thomas pers. comm.).

Since the 1950 to 1970 period there has been a considerable reduction in the *Coleophora* spp. population. It is probable that three major factors, operating sequentially, were responsible for this reduction. The first was a change in clover seed crop management practices. Before 1970 seed was often harvested from a crop for two years. This allowed the *Coleophora* spp. population to build up to a high level and to be especially damaging in the second year (French 1972). The general level of damage reduced when growers included white clover as a single year crop in a set rotation. More specialist growers also managed their crops to produce a sharp peak of flowering in mid-December followed by harvesting in mid-January. This practice decreased the success of the second *C. frischella* generation by greatly reducing the habitat available to them, and consequently reduced the overwintering population.

The second factor was the establishment of the two parasitoids, *B. variegator* and *Chrysonotomyia trifolii*. In Canterbury, the primary seed growing area, these parasitoids established in 1970 and 1977 respectively, and populations grew rapidly. *Coleophora* spp. populations were monitored over this period using a 'drag' method (Pearson 1975). A 20 m drag sample in a white clover seed crop at mid-December in 1969 or 1970 produced a yield of about 24 *Coleophora* spp. moths; by 1977 the same situation captured less than two moths (Pearson unpublished), a ten fold reduction. Much of this reduction can probably be attributed to *B. variegator*. *Chrysonotomyia trifolii* is also a successful parasitoid and is now spread throughout the seed growing areas of New Zealand. The outcome of competition between *C. trifolii* and *B. variegator* in the same host larva is unknown but the former established rapidly in Canterbury when the latter had been present and successful for seven

years. *B. variegator* selects later instar larvae than *C. trifolii* and will have been partially displaced if it rejects previously parasitised larvae as hosts.

The third factor which has contributed to the *Coleophora* spp. population reduction is the introduction of the blue-green lucerne aphid *Acyrthosiphon kondoi* Shinji in 1975 and the pea aphid *A. pisum* (Harris) in 1976. *A. kondoi* has been shown to cause yield reductions in white clover seed crops (Trought 1977) and insecticidal control has frequently been applied to crops infested with blue-green and pea aphids. The same insecticides, and frequently the same timing, are used for both aphid and casebearer control, so that sub-economic casebearer populations have often been even further reduced because of the presence of aphids in crops.

Conclusions

The parasitoids which have established, *B. variegator* and *Chrysonotomyia trifolii*, are not those which were deemed to be the most desirable. However, in the absence of competition from the more closely synchronized parasitoids, *Agathis rufipalpis* and *Chelonus contractus*, they have achieved the aim admirably. It is now rare for *Coleophora* spp. infestations in white clover seed crops to reach an economically damaging level or require control with insecticides.

Literature Cited

Benander, P. (1939) Die Coleophoriden Schwedens. *Opuscula entomologicae* 4, 30-110.

Bradley, J.D. (1967) Some changes in the nomenclature of British Lepidoptera. Part 5. Microlepidoptera. *Entomologists gazette* 18, 45-47.

Cawthron Institute (1953) Annual Report 1952-53, 36.

Chalmers-Hunt, J.M. (1975) Notes on the Coleophoridae. *Proceedings and Transactions of the British Entomological and Natural History Society* 7(3), 74-87.

Delucchi, V.; Verbeke, J. (1954) *Habrocytus milleri* n. sp., ectoparasite de *Coleophora frischella* L. *Bulletin Institut Royal des Sciences Naturelles de Belgique* 29(3), 1-14.

DSIR, Entomology Division, File BC 1/4.

Dugdale, J.S. (1988) Lepidoptera: an annotated catalogue, and keys to family group data. Fauna of New Zealand 14, 262 pp.

Dumbleton, L.J. (1952) Coleophoridae (Lep.) as pests of clovers. *New Zealand journal of science and technology* 33(A), 109-112.

Dumbleton, L.J. (1959) Clover case-bearers. New Zealand Department of Agriculture, bulletin No. 216, 4 pp.

Dumbleton, L.J. (1963) The biology and control of *Coleophora* spp. (Lepidoptera- Coleophoridae) on white clover. *New Zealand journal of agricultural research* 6, 277-292.

Dumbleton, L.J. (1964) Biology and control of the clover case-bearer. *Proceedings of the 17th New Zealand Weed and Pest Control Conference*, 161-164.

Entomology Division, DSIR (1977) Annual Report, p 53.

Entomology Division, DSIR (1978) Annual Report, p 64.

French, R.A. (1972) Clover case-bearers in New Zealand. *Proceedings of the 25th New Zealand Weed and Pest Control Conference*, 220-223.

Hackman, W. (1945) Die Coleophoriden Finnlands. *Notulae entomologicae* 25, 1-63.

Hamilton, A. (1944) *Coleophora spissicornis* Haw., the clover case-bearer in New Zealand. *New Zealand journal of science and technology* 25(A), 269-273.

Hooker, J.D. (1864-1867) Handbook of the New Zealand flora. Reeve and Co. London. 798 pp.

Hoy, J.M. (1960) Preliminary assessment of toxaphene, strobane and thiodan for control of clover case-bearers (*Coleophora* spp.) (Coleophoridae Lepidoptera). *New Zealand journal of agricultural research* 3, 617-622.

Jalava, J. (1977) *Coleophora frischella* and *Coleophora alcyonipennella* (Lepidoptera, Coleophoridae) in eastern Fennoscandia. *Notulae entomologicae* 57, 29-31.

Kelsey, J. (1958) Damage by clover case-bearer caterpillars. *New Zealand journal of agricultural research* 1, 525-526.

Lindsay, S. (1927) On the occurrence, in New Zealand of *Coleophora fabriciella* Villers. *New Zealand journal of science and technology* 9, 248-249.

Lobb, W.R.; Wood, J. (1971) Insects in the food supply of starlings in mid-Canterbury. *New Zealand entomologist* 5, 17-24.

Patterson, S.C. (1930) List of Lepidoptera at Whangarei. *Transactions of the New Zealand Institute* 61, 554-561.

Pearson, W.D. (1975) Ecology of *Coleophora spissicornis* (Haworth) and *C. frischella* (Linnaeus) associated with *Trifolium repens* Linnaeus in Canterbury, New Zealand. Ph.D. thesis, University of Canterbury, Lincoln College, New Zealand. 242 pp.

Pierce, F.N., Metcalfe, J.W. (1935) *The genitalia of the tineid families of the Lepidoptera of the British Isles*. Pierce, Oundle, London. 116 pp.

Stuart, A.M. (1957) *Ephialtes brevicornis* (Grav.) as an external parasite of the diamond-back moth, *Plutella maculipennis* (Curt.). *Bulletin of entomological research* 48, 477-488.

Stuart, A.M. (1958) A review of work in New Zealand on the clover case-bearers *Coleophora spissicornis* Haw. and *C. alcyonipennella?* Kollar (Coleophoridae, Lep.). *New Zealand journal of agricultural research* 1, 239-248.

Taylor, T.H.C. (1937) The biological control of an insect in Fiji. Imperial Institute of Entomology, London. 239 pp.

Thomas, W.P. (1969) The establishment in New Zealand of *Bracon variegator* Nees (Hymenoptera: Braconidae) a parasite of *Coleophora* species (Lepidoptera: Coleophoridae). *New Zealand journal of science* 12, 43-53.

Trought, T.E.T. (1977) Control of blue-green lucerne aphid on white clover seed crops. *Proceedings of the 30th New Zealand Weed and Pest Control Conference*, 188-191.

Verbeke, J. (1952) Report on *Coleophora frischella* L. and its parasites Europe. CIBC unpublished report, 31 pp.

Verbeke, J. (1957) Biology and parasites of *Coleophora frischella* Linnaeus (Lepidoptera: Coleophoridae). *Bulletin Institut Royal des Sciences Naturelles de Belgique* 33(41), 1-27.

Zwölfer, H. (1961a) Coleophora project, Interim Report (March 16, 1961). CIBC unpublished report, 17 pp.

Zwölfer, H. (1961b) Coleophora project, Interim Report (September, 1961). CIBC unpublished report, 23 pp.

Zwölfer, H. (1961c) Coleophora Project, Interim Report (November, 1961). CIBC unpublished report, 13 pp.

Zwölfer, H. (1961d) A comparative analysis of the parasite complexes of the European fir budworm, *Choristoneura murinana* (Hub.) and the North American spruce budworm, *C. fumiferana* (Clem.) *Commonwealth Institute of Biological Control, technical bulletin* 1, 1-162.

Zwölfer, H. (1962) Coleophora Project, Interim Report (October, 1962). CIBC unpublished report, 9 pp.

Zwölfer, H. (1968) Investigations on *Coleophora alcyonipennella* Kol. and its parasites. CIBC, Report for 1964-1967. Part 1. January 1968.

Helicoverpa armigera (Hübner), tomato fruitworm (Lepidoptera: Noctuidae)

P.J. CAMERON

Pest Status

Helicoverpa armigera (Hübner) is widely distributed through Africa, Europe, Asia, Australia and the South Pacific. In New Zealand it is referred to as the sub-species *conferta* (Walker) (Butcher 1984). *H. armigera* occurs throughout New Zealand but is more common as a pest species in the North Island and northern South Island. Its host range is wide, and as large larvae feed mainly on flowers and fruit, significant economic damage can be caused at low population densities. In cultivated crops, it is most important as a pest of tomatoes, sweetcorn and beans. It is of minor importance on capsicums, peas, pumpkins, legume seed crops and various ornamental plants and can also cause damage in most home gardens. It has numerous wild host plants including legumes and composites which provide large reservoirs from which this pest can reinfest crops. Cotton, pulses, sorghum and tobacco on which *Helicoverpa* and *Heliothis* spp. are notable pests overseas are uncommon in New Zealand.

In New Zealand *Helicoverpa armigera* diapauses over winter in the pupal stage. Adults first appear in October or November but are not common until January. Larvae appear in early tomato crops in the first week of December and numbers increase on later annual and perennial crops until February or March. On tomatoes, eggs are laid on the higher parts of the plant, often on the upper surface of leaves and sometimes on the flowers. Small larvae rarely move more than 10 cm which means that most of them do not find and damage fruit until they grow to approximately 10 mm in length (Cameron & Valentine 1985). Therefore, parasitoids which kill larvae before they reach this critical size will reduce the immediate crop damage as well as reducing pest numbers.

Background

The only naturally occurring common parasitoid of *H. armigera* prior to biological control introductions was a *Trichogrammatoidea* sp. which was found by R.A. Cumber in 1974 (DSIR files). He recorded 73-98% parasitism of eggs at Paihia and 60-93% parasitism in Auckland, both on tomatoes. R.L. Hill (DSIR files) similarly recorded high levels (89%) of parasitism in Northland. Recent systematic sampling in tomatoes in Auckland (Cameron unpublished) suggests that high rates of egg parasitism occur only late in the season.

In New Zealand the larval stage was rarely parasitised prior to biological control introductions. This contrasts with the presence of numerous parasitoids of *Helicoverpa* and *Heliothis* spp. throughout their continental distribution (Greathead & Girling 1982). Cumber & Eyles (1961) suspected that *Apanteles ruficrus* (Haliday) was a larval parasitoid of *Helicoverpa armigera* in New Zealand but this is not supported by our rearing records (Cameron & Valentine 1985, Cameron unpublished). Hill *et al.* (1985) found that *A. ruficrus* would not develop on *H. armigera*, a result confirmed by Michael *et al.* (1984). The only naturally occurring but rare parasitoid is a *Rogas* sp. (Braconidae), which has been recorded on only two occasions from *H. armigera* larvae in tomatoes in Auckland (Cameron unpublished).

In Australia there are several parasitoids which attack larvae and emerge from pupae (Room 1979), but low rates of parasitism (Wilson 1983) suggest that these are opportunistic parasitoids of *H. armigera*. Two species of ichneumonids, *Ichneumon* (= *Pterocormus*) *promissorius* Erichson and *Echthromorpha intricatoria* (F.), have been recorded from *H.*

armigera in New Zealand (Valentine & Walker 1989). *Lissopimpla excelsa* (Costa) and *Netelia producta* (Brullé) parasitise *H. armigera* in Australia but have been recorded only from other hosts in New Zealand.

Only two predators, *Cermatulus nasalis* (Westwood) and *Oechalia schellembergii* (Guérin-Méneville) (Pentatomidae), are recorded by Valentine (1967). *Nabis kinbergii* (Reuter) and *Micromus tasmaniae* (Walker) are commonly found with *H. armigera* and are also considered to be predatory (Cameron & Valentine 1985). Several species of spiders, ants, Coccinellidae and Miridae may also contribute to predation, as they do in Australia (Room 1979).

The present control practice for *H. armigera* on tomatoes involves insecticide treatment every two to three weeks after fruit begins to set. This can require more than five applications despite which fruit damage still occurs between sprays or in poorly treated areas. Sweetcorn usually requires only one application after the silks begin to turn brown. In other susceptible crops *H. armigera* is usually treated with insecticides intended for control of other pests. The chemicals recommended for control of *H. armigera* are effective only if they are applied before larvae penetrate fruit. Synthetic pyrethroids are widely used and their continued effectiveness in New Zealand indicates that resistance has not developed in *H. armigera* here, despite its occurrence in Australia. The probability of Australian migrant adults or locally selected individuals causing the development of insecticide resistance in New Zealand may be reduced by the use of non-chemical alternatives including biological control.

Importations, Releases and Recoveries

Parasitoids of larval *H. armigera* were imported from India in 1969 from Bulgaria and Greece in 1976-77 (Hill *et al.* 1985), and from the U.S.A in 1986-87 (Cameron unpublished) (Table 14.1). *Trichogramma* spp. were also released to attack a range of noctuid pests including *H. armigera* (see Chapter 21).

One ichneumonid and three tachinids were received from the Indian Station of CIBC in 1969 (Table 14.1). These were reared on *H. armigera* and used in a brief release programme late in the season. Hill *et al.* (1985) indicate that relatively few individuals were released: 81 *Campoletis chlorideae* Uchida, 128 *Carcelia illota* (Curran), 244 *Palexorista laxa* (Curran) and 650 *Eucelatoria armigera* (Coquillett). No recoveries were made.

Two parasitoids which kill small *H. armigera* larvae were imported from Europe in 1976-77 (Carl 1978). *Hyposoter didymator* (Thunberg) was not released because it was shown to have a wide host range which gave concern about possible environmental conflicts (Hill *et al.* 1985). The other parasitoid, *Apanteles kazak* Telenga was reared and released (Singh *et al.* 1982).

Apanteles kazak Telenga (Hymenoptera: Braconidae)

A. kazak is a specific parasitoid of *Helicoverpa* and *Heliothis* spp. It was collected from *Helicoverpa armigera* in southern Europe by CIBC (Carl 1977) and reared on *Heliothis virescens* (F.) for shipment to New Zealand in 1977 (Carl 1978). Approximately 3,500 adults or parasitised larvae were released over two seasons from 1978 to 1980 (E.P. Burgess DSIR files, Hill *et al.* 1985). Thirty release sites were located in Northland, Auckland, Bay of Plenty and Gisborne (Cameron & Valentine in press). Recoveries are documented in Cameron & Valentine (in press) and indicate that widespread establishment was obtained in the vicinity of all release sites by 1982. Natural dispersal of approximately 100 km per year has spread the parasitoid into the Waikato and Hawke's Bay, but not to the Manawatu. *A. kazak* was redistributed to Marlborough in 1985 through the release of 85 cocoons at one lucerne site. Recoveries from four sites in 1987 indicate that it has established.

Table 14.1 Parasitoids imported into New Zealand for control of *Helicoverpa armigera*, and the synonomy for species imported under other names.

Parasitoid (Synonymy)	Origin	Date	Status
HYMENOPTERA: BRACONIDAE			
Apanteles kazak Telenga (= *Cotesia kazak* (Telenga))	Europe	1977	Established
Glabromicroplitis croceipes (Cresson) (= *Microplitis croceipes* (Cresson))	U.S.A.	1986	Recovered
ICHNEUMONIDAE			
Campoletis chlorideae Uchida (= *Ecphoropsis perdistinctus* (Viereck))	India	1969	Not recovered
Hyposoter didymator (Thunberg)	Europe	1976	Not released
TRICHOGRAMMATIDAE (see Chapter 21)			
DIPTERA: TACHINIDAE			
Eucelatoria armigera (Coquillett)	India	1969	Not recovered
Carcelia illota (Curran) (= *Eucelatoria illota* (Curran)	India	1969	Not recovered
Palexorista laxa (Curran)	India	1969	Not recovered

Glabromicroplitis (= *Microplitis*) *croceipes* (Cresson) (Hymenoptera: Braconidae)

G. croceipes is a North American parasitoid of *Helicoverpa* and *Heliothis* spp. which was first imported from the USDA at Stoneville, Mississippi in 1986. This species prefers host larvae slightly larger (Powell & King 1984) than those preferred by *A. kazak*. It is the most successful and wide-ranging parasitoid of *Helicoverpa* and *Heliothis* spp. in the U.S.A. (Puterka *et al.* 1985). *G. croceipes* has been successfully reared on *Helicoverpa armigera* in New Zealand. Releases commenced in January 1987 in Auckland, Gisborne and Hastings, and minor recoveries have been made in each of these areas.

Evaluation

The brief attempts to introduce one ichneumonid and three tachinids from India in 1969 (Table 14.1) give no clear indication of the suitability of these species for New Zealand conditions. However, the lack of host larvae due to diapause of *H. armigera* in high southern latitudes is likely to have been a major difficulty for these parasitoids. Extensive releases of *Campoletis chlorideae* in Western Australia have resulted in recoveries only from irrigated areas where *Helicoverpa* spp. are active throughout the year (Michael in press). Although New Zealand crops and the climate differ from those in India where the parasitoids originated, the failure to obtain establishments could equally have resulted from the *ad hoc* nature of the programme.

The impact of *A. kazak* on *H. armigera* larvae and the damage they cause has been examined in unsprayed tomatoes and beans (Cameron & Valentine 1985). The larval size structure of populations with and without *A. kazak* was assessed but no attempt was made to determine the effect on population density of *H. armigera*. The study showed that at levels of 45% parasitism, fewer larvae reached damaging size and larval damage was less in

both crops. By 1986, rates of parasitism frequently exceeded 60% and *A. kazak* limited the damage by *H. armigera* in all crops examined. However, in unsprayed tomato crops, those *H. armigera* which escaped parasitism caused over 20% fruit damage. This prompted the importation of *G. croceipes*, and research on the use of selective control agents such as *Bacillus thuringiensis* Berliner.

Conclusions

The establishment of *A. kazak* has had a significant effect on the larval size distribution of *H. armigera* and has produced a reduction in crop damage. It may also have reduced the overall population but this would be very difficult to demonstrate. *A. kazak* is of most benefit in processing crops, and fresh crops where damage can be graded out. The parasitoid occurs in commercial crops where it attacks *H. armigera* which reinvade between insecticide applications. As *A. kazak* now provides some protection between sprays it may be possible to reduce spray frequency. However, the number of *H. armigera* larvae still causing damage in unsprayed crops is sufficient to warrant the introduction of further species and *G. croceipes* appears to be the best additional biological control agent available at present to complement *A. kazak*.

As there are comparatively few parasitoids of *H. armigera* established in New Zealand there is still wide scope for the introduction of further species, particularly those parasitic on eggs and small larvae. Natural populations of *Trichogramma pretiosum* Riley gave high rates of parasitism in tropical Australia (Michael in press), but Wilson (1982) noted very low parasitism by Trichogrammatidae further south. Our observations suggest that the effectiveness of the Trichogrammatidae may be limited by cool temperatures in New Zealand, as they are in southern Australia. Inundative releases can reduce *Helicoverpa* damage in temperate areas as shown by releases of *Trichogramma ivelae* Pang & Chen in tomatoes in New South Wales (McLaren &Rye 1981). Inundative releases of *Trichogramma* spp. may be uneconomic in New Zealand and any foreseeable efforts are likely to be confined to inoculative releases of strains or species originating from temperate climates (see Chapter 21).

The current selection of larval parasitoids has given preference to those species which kill larvae while they are still small. Future candidates include the braconids *Microgaster* spp. and *Apanteles* spp., and the ichneumonids *Campoletis* spp. The Australian species *Microgaster demolitor* (Wilkinson) achieves high rates of parasitism (Wilson 1982), but *Glabromicroplitis croceipes* has the advantage of a pupation site in the soil where it is protected from insecticides. *Apanteles marginiventris* (Cresson) has been imported from the U.S.A. to Australia for noctuid biological control, but Powell (in press) considered that it may compete with *A. kazak*. *Campoletis* spp. have a wide host range and parasitise *Helicoverpa* and *Heliothis* spp. on a wide range of crops. *C. chlorideae* is the most effective parasitoid of larval *Helicoverpa armigera* in India (Manjunath *et al.* in press) and *Campoletis sonorensis* (Cameron) occurs on a wide variety of crops in the U.S.A. (Puterka *et al.* 1985). Only one of these species should be imported as Lingren *et al.* (1972) have shown that interbreeding produces sterile offspring.

There is a large fauna including Ichneumonidae and Tachinidae which attack large larvae and pupae of *Helicoverpa* and *Heliothis* spp. These are often facultative parasitoids which do not achieve high rates of parasitism, and in crops they act after damage has occurred. Such parasitoids are not presently being considered for introduction, although they could add to the general natural enemy pressure against *H. armigera* populations.

Literature Cited

Butcher, M.R. (1984) Vegetable crop pests. Pp. 93-118 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Cameron, P.J.; Valentine, E.W. (1985) Evaluation of *Cotesia kazak* (Hymenoptera: Braconidae), a parasite of larval *Heliothis armigera conferta* (Lepidoptera: Noctuidae) in New Zealand. *New Zealand journal of agricultural research* 28, 545-553.

Cameron, P.J.; Valentine, E.W. (in press) Importation and establishment of new natural enemies of *Heliothis* into New Zealand. In Jackson, R.D.; King, E.G. (eds), Proceedings of workshop: Biological control of *Heliothis*, Amerind Press, New Delhi.

Carl, K.P. (1977) Survey, propagation and importation of natural enemies of *Heliothis armigera* Hb. Annual report for 1976. CIBC unpublished report.

Carl, C.P. (1978) *Heliothis armigera*; parasite survey and introduction of *Apanteles kazak* to New Zealand. Report of work in 1977-78. CIBC unpublished report.

Cumber, R.A.; Eyles, A.C. (1961) Insects associated with the major field crops in the North Island of New Zealand. IV. Hymenoptera. *New Zealand journal of agricultural research* 4, 390-408.

DSIR, Entomology Division, file BC 1/4.

Greathead, D.J.; Girling, D.J. (1982) Possibilities for natural enemies in *Heliothis* management and the contribution of the Commonwealth Institute of Biological Control. Pp. 147-158 in ICRISAT Proceedings of the international workshop on *Heliothis* management, November 1981, Patancheru, A.P., India.

Hill, R.L.; Cumber, R.A.; Allan, D.J. (1985) Parasitoids introduced to attack larvae of the Noctuidae (Lepidoptera), and their establishment in New Zealand (1968-78). DSIR Entomology Division report 5, 24 pp.

Lingren, P.D.; Wilson, F.D.; Sailor, R.I. (1977) Cross-mating of *Campoletis sonorensis* and *Campoletis chlorideae*. *Annals of the Entomological Society of America* 70, 442-446.

Manjunath, T.M.; Bhatnagar, V.S.; Pawar, C.S.; Sithanantham, S. (in press) Economic importance of *Heliothis* spp. in India and an assessment of their natural enemies and host plants. In Jackson, R.D.; King, E.G. (eds), Proceedings of workshop: Biological control of *Heliothis*, Amerind Press, New Delhi.

McLaren, I.W.; Rye, W.J. (1981) Occurrence of *Trichogramma ivelae* Pang and Cheng (Hymenoptera: Trichogrammatidae) and its use to control *Heliothis punctigera* Wallengren on tomatoes. *Journal of the Australian Entomological Society* 20, 110.

Michael, P.J. (in press) Importation and establishment of new natural enemies of *Heliothis* into Australia. In Jackson, R.D.; King, E.G. (eds), Proceedings of workshop: Biological control of *Heliothis*, Amerind Press, New Delhi.

Michael, P.J.; Woods, W.; Lawrence, P.J.; Fisher, W. (1984) Introduced parasites for the control of Australian noctuid pests. Pp. 294-303 in Bailey, P.; Swincer, D. (eds.), *Proceedings of the 4th Australian applied entomological research conference*, Adelaide, Australia.

Powell, J.E. (in press) Importation and establishment of new natural enemies of *Heliothis* into the United States. In Jackson, R.D.; King, E.G. (eds), Proceedings of workshop: Biological control of *Heliothis*, Amerind Press, New Delhi.

Powell, J.E.; King, E.G. (1984) Behaviour of adult *Microplitis croceipes* (Hymenoptera: Braconidae) and parasitism of *Heliothis* spp. (Lepidoptera: Noctuidae) host larvae in cotton. *Environmental entomology* 13, 272-277.

Puterka, G.J.; Slosser, J.E.; Price, J.R. (1985) Parasites of *Heliothis* spp. (Lepidoptera: Noctuidae): Parasitism and seasonal occurrence for host crops in the Texas rolling plains. *Environmental entomology* 14, 441-446.

Room, P.M. (1979) Parasites and predators of *Heliothis* spp. (Lepidoptera: Noctuidae) on cotton in the Namoi Valley, New South Wales. *Journal of the Australian Entomological Society* 18, 223-228.

Singh, P.; Surrey, M.R.; Burgess, E.P.; Carey, G.P. (1982) A rearing method for *Heliothis armigera confertus* and its use for production of the parasitoid *Apanteles kazak* and two viruses. *New Zealand journal of zoology* 9, 301-308.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Valentine, E.W.; Walker, A.K. (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, (in press).

Wilson, A.G.L. (1982) Past and future *Heliothis* management in Australia. Pp. 343-354 in ICRISAT Proceedings of international workshop on *Heliothis* management, November 1981, Patancheru, A.P., India.

Wilson, A.G.L. (1983) Abundance and mortality of overwintering *Heliothis* spp. *Journal of the Australian Entomological Society* 22, 191-199.

Helix aspersa Müller, brown garden snail (Stylommatophora: Helicidae)

D.J. ALLAN

Pest Status

The brown garden snail *Helix aspersa* Müller was probably introduced into New Zealand on plant material from Britain or Europe in the early days of European settlement. It is widely distributed in New Zealand (Thomson 1922).

Snails feed on a wide variety of plants, with brassicas and other leafy vegetables sustaining the most obvious damage. Loose or cracked soil may allow access to root crops such as carrots or potatoes. Considerable economic loss can be sustained in flower or soft fruit crops where cosmetic damage is especially important. In commercial situations snails are regarded as pests of occasional significance in a wide variety of crops. *H. aspersa* is listed as one of the most important pest snails in Europe and is a quarantine pest for imports to the U.S.A. (Godan 1983). It is difficult to find any quantified reference to the actual significance or losses caused by *H. aspersa* in New Zealand (Butcher 1984, Proude 1970).

H. aspersa lays small clusters of eggs in topsoil in the spring, and these hatch in 10-12 days depending on the weather. There is one generation per year with maturity being reached after 10-12 months (Butcher 1984). Snails may live up to two years in suitable conditions. Weeds and other ground cover provide a suitable environment for development, and a refuge in which to escape predation.

In commercial crops, or where clean culture is practised, snails can be controlled with poisonous baits (Godan 1983, Proude 1970). *H. aspersa* is usually more significant as a pest in home gardens, or in weedy situations, where refuges exist for concealment.

Background

H. aspersa has no parasitoids in New Zealand. Predation provides the only form of natural enemy control. Exotic birds, especially the song thrush *Turdus philomelos* Behn and the blackbird *Turdus merula* L. were introduced in the 1860s. Hedgehogs *Erinaceus europaeus* L. were purposely introduced during the 1870s. Rodents such as rats and mice are also recorded as feeding on snails (Thomson 1922).

Gonaxis quadrilateralis (Preston) was introduced from Kenya into Hawaii in 1957 and was one of 11 predaceous snails and 10 predaceous beetles released for the control of the giant African snail *Achatina fulica* Bowdich. Five of these species were recovered, *G. quadrilateralis* being recorded as the most successful predator established (Davis 1961, Davis & Butler 1964). Therefore *G. quadrilateralis* was considered to be the most suitable species for importation for control of *H. aspersa* in New Zealand.

Importations, Releases and Recoveries

Vertebrates

The earliest releases of agents for snail control in New Zealand were in the early 1860s when thrushes and blackbirds were introduced. Not all those who introduced these birds had predation in mind, but in 1867 the abundance of slugs in Christchurch was used as an argument to support the further introduction of birds, especially thrushes, for the control of slugs and snails (Druett 1983). By 1881 thrushes were recorded as being abundant.

In 1879 the Hawke's Bay Acclimatisation Society discussed the introduction of hedgehogs to control insects. This was not carried through but many private liberations at about this time established hedgehogs which spread rapidly throughout the North and South Islands (Druett 1983).

Invertebrates

Lampyris noctiluca (L.) (Coleoptera: Lampyridae)

Clausen (1940) reported the introduction to New Zealand of the British glow-worm *L. noctiluca* to control *H. aspersa* in the 1930s, but Entomology Division DSIR has no specimens or records of this introduction.

Gonaxis quadrilateralis (Preston) (Gastropoda: Streptaxidae)

In January 1965, 295 live *G. quadrilateralis* were received in Auckland (Entomology Division DSIR) from C.J. Davis, Hawaii (Given 1965). In experimental tests *G. quadrilateralis* readily fed on *H. aspersa*. One hundred of these predatory snails were liberated in mid-January, 1965 at two sites in the Bay of Islands. At the main site some were released into cages which had previously been seeded with *H. aspersa*. Others were released directly into the field, into rank grass in the adjacent area. At the second site only field releases were made.

Inspections were made at both release sites for several years but no signs of live predators were seen. The remaining *G. quadrilaterlis* in the insectary in Auckland failed to survive the 1965 winter (DSIR files).

Evaluation

The introduction of exotic birds, especially thrushes and blackbirds, and the insectivorous mammal, the hedgehog, provide the only agents deliberately established for natural control of snails in New Zealand. These species are well adapted to the modified lowland areas where the snail problem exists.

With no detailed record of the introduction of *L. noctiluca* in the 1930s it is impossible to evaluate this introduction. The species has not been recovered in New Zealand.

G. quadrilateralis is of tropical origin (Davis & Butler 1964) and does not appear to have been able to survive the cool New Zealand winters, even in the northern regions. Reasonable numbers were liberated in favourable conditions and the culture failed to survive the winter in an unheated insectary. Further importations of this species appear unwarranted. C.J. Davis in correspondence with R.A. Cumber suggested that other predaceous snails, particularly *Euglandina* spp. from Florida or Texas, could be more suited to the New Zealand climate (DSIR files).

Conclusions

H. aspersa is still present in substantial numbers in most parts of lowland New Zealand, with predation by birds, hedgehogs, and rodents providing the only natural control.

Neither the glow-worm *L. noctiluca* nor the predaceous snail *G. quadrilateralis* appear to have established. There is little prospect for further use of general predators for the control of *H. aspersa*. This is partly due to the failure of previous introductions and partly due to the possible environmental conflicts of using polyphagous predators which may attack the indigenous snails.

A review of the known parasitoids and predators of slugs and snails is provided by Godan (1983).

At present, poisonous baits or sprays, and emphasis on weed removal are the major control methods available.

Acknowledgements

The review of *G. quadrilateralis* is based on research done by R.A. Cumber in 1965 (DSIR files).

Literature Cited

Butcher, M.R. (1984) Vegetable crop pests. Pp. 93-118 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Clausen, C.P. (1940) Entomophagous insects. McGraw-Hill, New York. 688 pp.

Davis, C.J. (1961) Recent introductions for biological control in Hawaii – vi. *Proceedings of the Hawaiian Entomological Society* 17, 389-390.

Davis, C.J.; Butler, G.D. (1964) Introduced enemies of the giant African snail, *Achatina fulica* Bowdich, in Hawaii (Pulmonata: Achatinidae). *Proceedings of the Hawaiian Entomological Society* 18, 377-389.

Druett, J. (1983) Exotic intruders: The introduction of plants and animals into New Zealand. Heinemann, Auckland. 291 pp.

DSIR, Entomology Division, file BC 1/4.

Given, B.B. (1965) Biological control of insect pests and noxious weeds. *Proceedings of the 18th New Zealand Weed and Pest Control Conference*, 223-228.

Godan, D. (1983) Pest slugs and snails: Biology and control. Springer-Verlag, Berlin. 441 pp.

Proude, C.K. (1970) The control of slugs and snails. *Proceedings of the 23rd New Zealand Weed and Pest Control Conference*, 216-219.

Thomson, G.M. (1922) The naturalisation of animals and plants in New Zealand. Cambridge University Press, London. 607 pp.

Listroderes difficilis Germain, vegetable weevil (Coleoptera: Curculionidae)

A.M. FERGUSON

Pest Status

The vegetable weevil *Listroderes difficilis* Germain, previously known as *L. costirostris* Schönherr or *L. obliquus* (Klug), was accidentally introduced into New Zealand, probably from Australia, sometime prior to 1930 (DSIR files). Initially, larvae were frequently found in the north of the North Island but May (1966) records its spread southwards to at least Oamaru (latitude 45°S). According to Lovell (1932) this weevil originated north of latitude 41°S in South America, especially southern Brazil, Argentina, Uruguay, and had spread into California, U.S.A. by about 1926. It also occurs in the Pacific Islands, Taiwan, Japan, South Africa, and was first recorded in Australia in 1905 (Wilson & Wearne 1962) where it is now widespread in all States.

As indicated by its common name, a large range of vegetable plants are hosts of this pest (Muggeridge 1933). Flower hosts include Iceland poppies, carnations, polyanthus and zinnias (DSIR files); mallow, chickweed, young thistles, capeweed (*Arctotheca calendula* (L.) Levyns, and hogcress (*Coronopus* sp.) are weed hosts. However, the preferred hosts of the larvae are carrots and turnips of any age, and of the adults, seedling tomato and potato plants (Muggeridge 1933). Both larvae and adults feed on plant foliage rather than the roots and damage caused by the latter is generally the more severe.

The life cycle of *L. difficilis*, which is somewhat unusual, has been described by May & Ferguson (1979). Adults emerge in spring yet oviposition does not commence until late summer, continuing throughout the winter except during the coldest months. *L. difficilis* reproduces parthenogenetically in New Zealand, whereas sexual reproduction is probably normal in the countries of origin (Kuschel 1972). Despite the presence of well-developed wings, adults have not been observed in flight but it is possible there is an autumn dispersal flight (Muggeridge 1933).

Plant damage in the 1930-1960 period was often severe enough to necessitate the re-planting of carrot, potato, and tomato crops (DSIR files). Currently, the pest status of the weevil varies in space and time, and despite such inconsistency it can still cause serious damage. Preventative pesticide applications are unwarranted. This is fortunate because the larvae are relatively difficult to kill, especially the later instars (Tappan 1974), and effective control requires more than one application of an insecticide at a high rate (Ferguson 1978).

The genus *Listroderes* contains many species. In addition to *L. difficilis*, *L. delaiguei* Germain (clover weevil) and *L. foveatus* (Lea) have established in New Zealand (Kuschel 1972) and Australia (Wilson & Wearne 1962). They are apparently economically unimportant although the clover weevil attacks clovers, tomatoes, potatoes and tobacco.

Background

There is a paucity of information referring to natural enemies of *L. difficilis* in New Zealand as no observations have been undertaken. Control strategies centre on insecticides, although cultivation, sowing into a weed-free environment, and crop rotation, have been suggested (Muggeridge 1933) and may help to alleviate the need for sprays. Unfortunately such cultural measures may also be deleterious to the soil-inhabiting cocoons of the *Stethantyx* spp. parasitoids (Nilsson 1985) which attack weevil larvae.

In 1957, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia introduced vegetable weevil parasitoids from Argentina and Uruguay (Wilson & Wearne 1962). These included *Epiplagiops littoralis* Blanchard (Tachinidae) which was liberated in the Capital Territory State that year. No recoveries were made, perhaps because an alternative host is necessary in the summer when *L. difficilis* is aestivating. Two ichneumonids, *Stethantyx argentinensis* (Blanchard) and *Stethantyx parkeri* (Blanchard) were also introduced in 1957-1958 along with the apparently accidental introduction of an undescribed parthenogenetic tersilochine (Wilson & Wearne 1962). Attempts to recover *Stethantyx* spp. in the field were limited but some *S. parkeri* were found in 1959 (Wilson & Wearne 1962).

In the U.S.A., Clancy (1969) also recorded the unintentional introduction of a parthenogenetic tersilochine during 1943-1946 when releases of *S. parkeri*, *S. argentinensis*, *E. littoralis*, and the braconid *Triaspis* sp. were made. Searches were undertaken from 1966 to 1968 but only the tersilochine had established and was found to cause an average of 4% (range 1.1-25.7) mortality in the host population (Clancy 1969).

Importations, Releases and Recoveries

The *Stethantyx* species bred well in the CSIRO laboratories and importations into New Zealand were arranged (DSIR files) in accordance with an agreement between CSIRO, DSIR and the Department of Agriculture, Entomology Research, Honolulu (B.B. Given pers. comm.). In August 1960, four shipments totalling 1,003 parasitised weevil larvae arrived in Nelson and 110 parasitoid cocoons resulted. These were incubated together with a further 1,000 cocoons imported in February 1961. Two hundred of these were dispatched in May 1961 for direct field liberation in Palmerston North. From the 910 cocoons remaining in Nelson, adults emerged from mid-April until early October 1961 in the following proportions: 245 male and 142 female *S. parkeri* and 180 male and 47 female *S. argentinensis*.

Laboratory rearing of both species was attempted from April 1961 onwards but foundered in July because of insufficient host numbers. Therefore all the remaining adults were released in Dodson's Valley, near Nelson, (48 male and 21 female *S. parkeri*; 30 male and four female *S. argentinensis*) and in the DSIR grounds, Nelson (six male and two female *S. parkeri*; three male *S. argentinensis*).

In August 1965, an unknown number of adults of an undetermined *Stethantyx* sp. or spp., were consigned from CSIRO, Australia, direct to Palmerston North for release (DSIR files).

The only attempt to ascertain establishment was undertaken in a survey in Palmerston North in August 1964 (DSIR files). In this exercise, 600 host larvae were collected, 438 weevil adults emerged but no parasitoids.

Evaluation

By inference from DSIR files, laboratory colonies of *Stethantyx* spp. were to be established at Nelson but releases of adults and/or cocoons were to be made at Palmerston North. However, the laboratory host population collapsed precipitating the release of adults in Nelson. At that time the host was, at best, difficult to locate around Nelson (W.P. Thomas pers. comm.) so there is some doubt about the suitability of the Dodson's Valley release site. *Stethantyx* spp. will parasitise larvae of all instars but those half grown are preferred (DSIR files). All of the adult parasitoids released in Nelson were liberated during August and September when the majority of the host population was probably in the soil-inhabiting prepupal and pupal stage and unavailable to the parasitoid.

Given this lack of synchrony, the uncertainty about host density and species, and the low numbers of *Stethantyx* spp. released, it would appear unlikely that this parasitoid established in Nelson.

The cocoons sent from Nelson to Palmerston North were released into one or two private gardens and again there is no mention in DSIR files of host species, presence or density. The adult *Stethantyx* sp. or spp. consigned in August 1965 directly from Australia to Palmerston North, arrived in a stressed condition which apparently occurred due to delays in transit. In consequence, a high mortality resulted but the remaining adults, number unstated, were apparently released into an area of high host numbers about DSIR grounds which provided a reasonable chance of establishment (DSIR files).

The proportions of *Stethantyx* species liberated in Nelson were known and could be assumed to reflect the species sent to Palmerston North as cocoons but the number which emerged there was not determined. Likewise, the species involved in the Australian consignment sent direct to Palmerston North was not recorded, so the parthenogenetic *Stethantyx* species may have been introduced.

Conclusions

With the problems encountered in this project it is most unlikely that *Stethantyx* spp. established in either Nelson or Palmerston North. Thus it is not surprising that there are no records of recoveries.

Further importations of biological control agents are probably unwarranted in view of the low pest status of *L. difficilis*. However, if future importation is contemplated it is suggested that consideration be given to obtaining a parthenogenetic parasitoid which attacks both *L. difficilis* and *L. delaiguei*.

Acknowledgements

Acknowledgement is extended to B.B. Given, then of Entomology Division, DSIR, Nelson, who was project leader. I also appreciate his verification and R.L. Hill's comments on this manuscript.

Literature Cited

Clancy, D.W. (1969) A new parasite of the vegetable weevil in southern California. *Journal of economic entomology* 62, 743-745.

DSIR, Entomology Division, file BC 1/4.

Ferguson, A.M. (1978) Insecticidal control of vegetable weevil larvae. *Proceedings of the 31st New Zealand Weed and Pest Control Conference*, 108-112.

Kuschel, G. (1972) The foreign Curculionoidea established in New Zealand (Insecta: Coleoptera). *New Zealand journal of science* 15, 273-289.

Lovell, O.H. (1932) The vegetable weevil *Listroderes obliquus*. *University of California College of Agriculture, Experimental Station bulletin* 546.

May, B.M. (1966) Identification of the immature forms of some common soil-inhabiting weevils, with notes on their biology. *New Zealand journal of agricultural research* 9, 286-316.

May, B.M.; Ferguson, A.M. (1979) Vegetable weevil, *Listroderes obliquus* (Klug) life cycle. *DSIR information series* 105/29.

Muggeridge, J. (1933) Some recently recorded exotic insect pests. *New Zealand journal of agriculture* 47, 221-228.

Nilsson, C. (1985) Impact of ploughing on emergence of pollen beetle parasitoids after hibernation. *Zeitschrift für angewandte Entomologie* 100, 302-308.

Tappan, W.B. (1974) Vegetable weevil: control in cigar-wrapper and flue-cured tobacco plant beds. *Journal of economic entomology* 67, 699-701.

Wilson, F.; Wearne, G.R. (1962) The introduction into Australia of parasites of *Listroderes obliquus* Klug. *Australian journal of agricultural research* 13, 249-257.

Mayetiola destructor (Say), hessian fly (Diptera: Cecidomyiidae)

R.P. MACFARLANE

Pest Status

The hessian fly *Mayetiola destructor* (Say), a native of Europe, arrived in New Zealand about 1873, probably in infested wheat straw from the U.S.A. (Kirk 1894) or Europe. By 1897 the hessian fly had spread to all the main cereal growing districts in New Zealand (Kirk 1898). It does not occur in Australia, nor apparently in Central and South America.

Wheat and rye are favoured hosts of hessian fly (Morrill 1982). The current hollow straw varieties of wheat in New Zealand are susceptible, but some barley varieties of English origin are resistant. Couch and barley grasses are also hosts (Jones 1936, 1939).

The importance of the hessian fly as a wheat pest declined as control measures improved and other important pests came to New Zealand. In 1892/3 most crop losses were moderate, i.e. 0-30% of the normal yield, but some crops barely justified harvesting (Kirk 1894). Yields declined by 12% as hessian fly spread during 1884-1898. From 1898-1912 wheat yields increased by 33% as the solid straw and hessian fly tolerant variety 'Tuscan' became more widely used and conditions for the crop improved (Hilgendorf 1939). By 1937/8 better cultivation by tractors enhanced cultural control of hessian flies. Now the hollow straw wheat and barley crops mainly have minimal losses due to hessian fly. In some years, a few crops suffer losses of up to 30% from lodging, when crop rotations and insufficient cultural control in the autumn/winter allow a hessian fly population to survive and subsequently increase. Crops in wetter districts and seasons, or those that are irrigated, tend to be more severely affected than those grown under drier conditions (Kirk 1894, Pike *et al.* 1983, Morrison 1938).

Larvae overwinter at the base of stems near or just below ground level and the first hessian flies emerge in spring. Females lay 100-150 eggs on the upper surface of leaves near the lower nodes (Enock 1891). In November/December the larvae feed on the stem and inner leaf directly above the nodes and pupate there, so they are protected by the leaf sheath. There is a second generation during January and February (Morrison 1938). The first generation mainly stunts crops and kills tillers, while the second generation causes lodging of stems and shrivelled seed. Both generations reduce the yield. Heavy infestations reach 4-8 million/ha (Forster & Taylor 1974, Nelson & Morrill 1978) and the fly can spread over several kilometres with assistance from the wind. Treated seed is probably the only effective chemical control (Nelson & Morrill 1978).

Background

Parasitoids in New Zealand

At least one parasitoid species established in New Zealand along with the host. Parasitoids were reared from the hessian fly pupae in early summer at Marton in 1888 and 1892 and at Masterton and Milton in 1893 (Kirk 1898), before parasitoids had been released. The parasitoids of 1888, which Maskell identified as probably Proctotrupidae, were almost certainly *Platygaster hiemalis* Forbes (Platygasteridae). This is the only proctotrupoid reported from hessian flies in New Zealand. It is specific to hessian fly.

A second parasitoid, *Macroneura vesicularis* (Retzius) (= *Eupelmus messene* Walker) (Eupelmidae) (Bouček 1988), was recorded in New Zealand by Walker in 1839. This polyphagous flightless parasitoid, can also be a hyperparasitoid. It is present in the South Island and could have affected hessian fly populations before 1894.

In addition to these records, in 1987 at Lincoln the author obtained only *M. vesicularis* from hessian fly pupae. However, near Geraldine *Aprostocetus zosimus* (Walker) (= *Tetrastichus charoba* Walker) and *Pediobius acantha* (Walker) (both Eulophidae) emerged from this host.

All these European parasitoids of hessian fly in New Zealand, and a further six European species, are established in North America (Krombein *et al.* 1979).

Parasitoids overseas

In the U.S.A. *Platygaster hiemalis* is slightly more common than any of the other 42 species of parasitoids of the hessian fly. It mainly affects the second generation with parasitism levels of 8-43% in the eastern States, 1-47% in North Central States (Hill *et al.* 1939, Hill 1953), and 40% in Georgia (Morrill 1982).

Pediobius epigonus parasitises small fly hosts and hessian fly larvae in grass stems in North America and Europe (Peck 1985). It lays its eggs within the host and so can begin parasitism earlier in the season than most chalcidoid parasitoids. In the U.S.A. maximum seasonal rates are 2-7% in hessian flies from the spring generation but in the autumn it ranges from 3-22%. In Europe this species tends to be relatively more important (Prasad 1969).

Pediobius acantha has fly and caterpillar hosts from grasslands in North America and the Palaearctic zone. It has not been recorded from hessian flies there, but this may be because it is very similar to *P. epigonus* in appearance.

Aprostocetus zosimus can complete two generations on the hessian fly. In the U.S.A. levels of parasitism in the spring and autumn generations are 0.2-7% and 0.5-34% respectively. This parasitoid is specific to hessian fly and three species of gall midge, and is occasionally a hyperparasitoid (Graham 1987). However the hessian fly is the only known primary host in New Zealand.

Macroneura vesicularis mostly affects the second generation of hessian flies. It is often a less common parasitoid, but Pike *et al.* (1983) found 39% parasitism of hessian fly by *M. vesicularis* in Washington State.

Importations, Releases and Recoveries

Some thousand hessian fly pupae with parasitoids were shipped from England in December 1893 and arrived in Wellington in the steamship 'Gothic' on 10 February 1894 (M. Galvin pers. comm., DSIR files). This was reported in the the Lyttelton Times of 1894. A further shipment, planned for 1894/5, may never have been sent (Kirk 1894, 1895). It is not certain how many parasitoids were imported. *Platygaster hiemalis* averages six adults/host, while all other parasitoids are solitary. Enock (1891) who supplied the parasitised hessian fly pupae reared 1.2 times more parasitoids than hosts. Thus the shipment from England probably contained more than a thousand parasitoids.

English sources considered that *P. hiemalis* and *Pediobius epigonus* (Walker) were the parasitoids in the hessian fly pupae shipped from England to New Zealand in 1894 (Kirk 1898). Shipments were sent to the eastern U.S.A. at the same time. Results from the North American importations suggest that it is likely that the shipment to New Zealand contained other species, including at least some of those reared by the author in 1987.

In February 1894, parasitoids were released near Masterton and perhaps Marton in the North Island (Kirk 1894, 1895), and Milburn and probably Milton in the South Island. The South Island releases were reported in the Bruce Herald on 23 February 1984. Subsequently, unidentified parasitoids of hessian flies were detected from Balfour in Southland, as well as from Timaru and Lincoln in Canterbury (Kirk 1898, Thomson 1922). There are no voucher specimens of parasitoids from hessian fly pupae collected between 1888 and 1943.

Platygaster hiemalis and *Pediobius epigonus* were reared from hessian fly pupae from Methven in 1944 (A. Hamilton unpublished, DSIR files). *Pediobius acantha* occurs in both the North and South Islands. *P. epigonus* occurs in the South Island, but has not been recorded from the North Island.

Evaluation

Most New Zealand records of levels of parasitism do not distinguish between the species of parasitoids. Early accounts could also have overestimated the rate of parasitism by not allowing for the emergence of more than one parasitoid from one host.

Levels of parasitism in 1892-3 at various sites ranged from 0-25% of fly pupae (Kirk 1898). In about 1919, parasitoids predominated over hessian flies collected from Balfour, but at Lincoln from 2-5% of the pupae produced parasitoids (Thomson 1922). In the 1930s, Morrison (1938) found a slight increase in parasitism as the season progressed, but during December and January it was not much more than 1%. A. Hamilton (DSIR files) collected a sample of heavily parasitised hessian fly pupae from Methven in January 1944. In 1987, the author found that 50% of hessian fly pupae taken from barley in January were parasitised with *Platygaster hiemalis* 38%, *Pediobius acantha* and *Aprostocetus zosimus* 6% each. In March, 40% of the hessian fly pupae from wheat were parasitised by *Macroneura vesicularis*.

Conclusions

The 1894 introduction of hessian fly parasitoids to New Zealand established *Pediobius epigonus* in addition to two species that had already become naturalised. Two other parasitoids, *Aprostocetus zosimus* and *Pediobius acantha* and perhaps some other chalcoid species, may have also established from this shipment.

The importation from England was partly redundant, because *Platygaster hiemalis* was already established, at least in the North Island, by 1893, and *M. vesicularis* was apparently present in the South Island. The importation could have enhanced the spread of *P. hiemalis* to the main cereal growing areas in the South Island and the introduced *P. epigonus* and *A. zosimus* both have some influence on the spring generation of hessian flies. The evaluation of the parasitoid complex of hessian flies in New Zealand has been inadequate to allow assessment of their impact on pest populations.

Whatever benefits accrued from the parasitoid introduction would have been greatest until the 1940s when modern cultural controls became more effective. Overall the introduction probably more than covered its costs. Introduced parasitoid species supplement control in situations, districts or on varieties that are more prone to attack.

Hessian fly populations could increase again if minimal or zero tillage is adopted. If so, spring generation parasitoids such as *Platygaster zosine* Walker could warrant introduction.

Acknowledgements

Z. Bouček, British Museum (Natural History), London, kindly confirmed the identification of the chalcid species (DSIR files). Staff at the Otago, Canterbury, National Museums, the Canterbury Public Library and National Archives helped by tracing records of voyages of the 'Gothic' and by checking newspaper reports and insects in their collections. J. Berry, DSIR, Auckland, helped locate files and handle specimens from the National Arthropod Collection.

Literature Cited

Bouček, Z. (1988) Australasian Chalcidoidea (Hymenoptera). CAB International, Wallingford, U.K. 832 pp.

DSIR, Entomology Division, file BC 1/4.

Enock, F. (1891) The life history of the hessian fly *Cecidomyia destructor* Say. *Transactions of the Entomological Society, London*, 329-366.

Forster, J.E.; Taylor, P.L. (1974) Estimating populations of the hessian fly. *Environmental entomology* 3, 441-445.

Graham, M.W.R. (1987) A reclassification of the European Tetrastichinae (Hymenoptera: Eulophidae), with a revision of certain genera. *Bulletin of the British Museum (Natural History) Entomology series* 55, 1-392.

Hilgendorf, F.W. (1939) Wheat in New Zealand. Whitcomb and Tombs, Auckland, 134 pp.

Hill, C.C. (1953) Parasites of the hessian fly in the north central states. *United States Department of Agriculture circular* 923, 15 pp.

Hill, C.C.; Pinckney, J.S.; Udine, E.J. (1939) Status and relative importance of the parasites of the hessian fly in the Atlantic states. *United States Department of Agriculture technical bulletin* 689, 15 pp.

Jones, E.T. (1936) *Hordeum* grasses as hosts of the hessian fly. *Journal of economic entomology* 29, 704-710.

Jones, E.T. (1939) Grasses of the tribe Hordeae as hosts of the hessian fly. *Journal of economic entomology* 32, 505-510.

Kirk, T.W. (1894) A brief history of the hessian fly in New Zealand. *Report of the Department of Agriculture*, 83-87.

Kirk, T.W. (1895) Natural enemies of the hessian fly *Semiotellus nigripes* (= *Entedon epigonus*). *Report of the Department of Agriculture*, 161.

Kirk, T.W. (1898) Hessian fly *Cecidomyia destructor*. *Report of the Department of Agriculture*, 171-174.

Krombein, K.V.; Hurd, P.D.; Smith, D.R.; Burks, B.D. (1979) Catalogue of Hymenoptera in America north of Mexico. Vol. 1 Symphyta and Apocrita. Smithsonian Institution Press, Washington, D.C. 1193 pp.

Morrill, W.L. (1982) Hessian fly: host selection and behaviour during oviposition, winter biology and parasitoids. *Journal Georgia Entomological Society* 17, 156-167.

Morrison, L. (1938) Survey of the insect pests of wheat crops in Canterbury and north Otago during the summers of 1936-37 and 1937-38. *The New Zealand journal of science and technology* 20A, 142-155.

Nelson, L.R.; Morrill, W.L. (1978) Hessian fly control in wheat by suppression of fall generations with carbofuran. *Agronomy journal* 70, 139-141.

Peck, O. (1985) The taxonomy of the Nearctic species of *Pediobius* (Hymenoptera: Eulophidae), especially Canadian and Alaskan forms. *The Canadian entomologist* 117, 647-704.

Pike, K.S.; Hatchett, J.H.; Antonelli, A.L. (1983) Hessian fly (Diptera: Cecidomyiidae) in Washington: distribution, parasites and intensity of infestations on irrigated and non irrigated wheat. *Journal Kansas Entomological Society* 56, 261-266.

Prasad, S.N. (1969) Measures employed to control gall midge infestation 3. Biological control (Diptera, Cecidomyiidae). *Cecidologia Indica* 4, 43-57.

Thomson, G.M. (1922) Naturalisation of animals and plants in New Zealand. Cambridge University Press, Cambridge, 607 pp.

Metopolophium dirhodum (Walker), rose-grain aphid (Homoptera: Aphididae)

M.W. STUFKENS and J.A. FARRELL

Pest Status

Metopolophium dirhodum (Walker), was first collected in New Zealand in April 1982, in Auckland Province (R. Sunde pers. comm.) and at about the same time in a suction trap at Lincoln, Canterbury (Farrell & Stufkens unpublished). Origin and mode of entry into New Zealand are unknown. The aphid spread rapidly throughout the country and populations reached 200/tiller on Canterbury cereal crops in early December 1982. The host range comprises barley, oats, wheat, rye, and grasses such as phalaris and prairie grass. *M. dirhodum* is rarely found on ryegrass, and the species appears to maintain itself on an annual cycle of cereal crops: regrowth, forage oats, winter and spring cereals. No sexual forms have been found in New Zealand, and the life cycle is anholocyclic (Stufkens & Farrell 1985b). Infestations of 100 aphids/tiller or more may cause loss of yield in excess of 10% in spring barley and oats, but application of an organo-phosphate spray at the flagleaf stage controls aphid outbreaks in these crops (Stufkens & Farrell 1985a).

Background

Natural enemies of *M. dirhodum* have been observed at Lincoln during spring. First to appear are lacewings *Micromus tasmaniae* (Walker) (Neuroptera: Hemerobiidae) the eggs being visible in short rows on leaf blades, while larvae are hidden at the base of plants during the day. Ladybirds (*Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae)) appear later, particularly in open, spring-sown crops, followed by syrphids *Melanostoma fasciatum* (Macquart), *Melangyna novaezelandiae* (Macquart) (Diptera: Syrphidae). Ground dwelling spiders and polyphagous beetles also are predators of *Metopolophium dirhodum*.

Fungus diseases (*Zoophthora aphidis* Remaudière & Hennebert, *Entomophthora planchoniana* Cornu, *Conidiobolus obscurus* (Hall & Dunn) Remaudière & Kell – R.J. Milner pers. comm.) are important mortality factors in Canterbury in some seasons (Farrell & Stufkens unpublished).

Parasitised aphids (mummies) were rarely found before 1985. *Aphelinus* sp. (Hymenoptera: Aphelinidae) attack *Metopolophium dirhodum* in the glasshouse: one mummy of this species was found in the field. *Aphidius ervi* Haliday (Hymenoptera: Aphidiidae) is occasionally reared from *M. dirhodum* in Canterbury, more frequently in the Manawatu (P. McGregor pers. comm.), and is a common parasitoid of *M. dirhodum* in western Europe (Rabbasse & Dedryver 1983). The introduction of a further parasitoid species was planned in 1985. *Aphidius rhopalosiphi* (De Stefani Perez) was recorded as the most frequent parasitoid in southern England (Dean *et al.* 1981) and western France (Rabasse & Dedryver 1983). It was therefore chosen for introduction (Stufkens & Farrell 1987).

Importations, Releases and Recoveries

Aphidius rhopalosiphi was supplied from southern England by W. Powell and from western France by J.-M. Rabasse. Two shipments of 250 and 1,000 *M. dirhodum* mummies were

received at the Lincoln quarantine laboratory in April and June 1985, respectively. *A. rhopalosiphi* was reared through three generations in the laboratory in order to exclude hyperparasitoids and disease from the stock. Rose-grain aphid colonies feeding on potted barley plants were provided as hosts, maintained under a temperature/light regime of 18°C (16 h day) – 15°C (8 h night).

Releases were made between June 1985 and January 1987 at 20 sites, throughout the South Island and in the Manawatu in the North Island (one site), in cereal crops infested with *M. dirhodum*. Approximate numbers of mummies released in Southland (8,000), Mid Canterbury (163,000), North Canterbury (7,000), Marlborough (3,000) and the Manawatu (5,000) totalled 186,000.

Recoveries were made during surveys (inspection of cereal foliage for about 10 minutes/observer) of 197 cereal crops throughout the South Island during November and December 1986. *A. rhopalosiphi* was found at 93 sites (47%) in all areas except Marlborough and the Manawatu. In addition, three hyperparasitoids, *Alloxysta victrix* (Westwood) (= *A. infuscata* (Kieffer)), *Pachyneuron aphidis* (Bouché) and *Dendrocerus* sp., were reared from the *M. dirhodum* mummies (Stufkens & Farrell 1987). In 1987, numerous *Aphidius rhopalosiphi* were recovered from cereal crops in Southland, Otago, Canterbury, Marlborough and the Manawatu (Stufkens unpublished, P. McGregor pers. comm.).

Evaluation

A. rhopalosiphi population density and rate of parasitism of *M. dirhodum* were evaluated in Canterbury in October-December 1986. At Lincoln, 14 weekly samples of 360 barley tillers yielded 5,466 rose-grain aphids and 239 mummies (from which only *A. rhopalosiphi* was reared). The parasitoid/prey ratio of 1:23 is comparable with that recorded for these species in southern England (Dean *et al.* 1981). *A. rhopalosiphi* were numerous (up to 0.2/tiller) in spite of low aphid numbers (2/tiller). Near Rangiora, greater aphid numbers (12/tiller – mean of 15 sites) supported 0.5 *A. rhopalosiphi*/tiller. This population is comparable with that reported from western France by Rabasse & Dedryver (1983) (Stufkens & Farrell 1987).

Conclusions

A. rhopalosiphi spread rapidly in Canterbury Province, where populations were comparable with those in western Europe, throughout the South Island and in the southern North Island. *A. rhopalosiphi* appears to be a useful addition to the range of biotic regulatory agents acting against rose-grain aphid and quantification of its impact may be possible in the future.

Literature Cited

Dean, G.J.; Jones, M.G.; Powell, W. (1981) The relative abundance of the hymenopterous parasites attacking *Metopolophium dirhodum* (Walker) and *Sitobion avenae* (F.) (Hemiptera: Aphididae) on cereals during 1973-79 in southern England. *Bulletin of entomological research* 7, 307-315.

Rabasse, J.M.; Dedryver, C.A. (1983) Biologie des pucerons des céréales dans l'ouest de la france. III. Action des hyménoptères parasites sur les populations de *Sitobion avenae* F., *Metopolophium dirhodum* Wlk. et *Rhopalosiphum padi* L. *Agronomie* 3, 779-790.

Stufkens, M.W.; Farrell, J.A. (1985a) Yield responses in cereals treated with pirimicarb for rose-grain aphid control. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 188-190.

Stufkens, M.W.; Farrell, J.A. (1985b) Observations of the phenology of rose-grain aphids in mid-Canterbury. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 184-187.

Stufkens, M.W.; Farrell, J.A. (1987) Establishment of *Aphidius rhopalosiphi*, a parasitoid of the rose-grain aphid in New Zealand. *Proceedings of the 40th New Zealand Weed and Pest Control Conference*, 15-18.

Mythimna separata (Walker), cosmopolitan armyworm (Lepidoptera: Noctuidae)

M.G. HILL and D.J. ALLAN

Pest Status

Mythimna separata (Walker) is a major defoliating pest of graminaceous crops in Asia and Oceania (Sharma & Davies 1983). In New Zealand it was a major pest of pasture and grain crops in the North Island and the northern part of the South Island (Cumber *et al.* 1977, Kain *et al.* 1968) until the early 1970s when a strain of *Apanteles* (= *Cotesia*) *ruficrus* (Haliday) was introduced from Pakistan (Cumber *et al.* 1977). It is now a minor pest of pasture and grain crops in the northern part of the North Island. It has three to four generations per year, and outbreaks occur in summer and early autumn (January to March).

Background

M. separata is attacked by a wide range of indigenous parasitoids (Table 19.1). In addition to the list in Table 19.1, Clearwater (1971) records *Diphyus gradatorius* (Thunberg) as a pupal parasitoid; however this is not recorded by Valentine & Walker (1989) in their review. An indigenous strain of *A. ruficrus* parasitised *M. separata* larvae prior to introductions of a different strain from Pakistan (Valentine 1967). Both *Ichneumon promissorius* Erichson and *Lissopimpla excelsa* (Costa) can be important pupal parasitoids, causing density dependent mortality (Hill 1988). It is also attacked by several diseases which can kill a significant proportion of larvae in late summer populations (Hill *et al.* 1985).

Importations, Releases and Recoveries

In 1971/72, a different strain of *A. ruficrus* was introduced from Pakistan. This was field collected from *Agrotis ipsilon* (Hufnagel) (Mohyuddin & Shah 1977) and was reared prior to field release on *A. ipsilon* and *M. separata* in New Zealand (Cumber *et al.* 1977).

Table 19.1 Parasitoids of *Mythimna separata* in New Zealand (after Valentine & Walker 1989)

LARVAL PARASITOIDS
Apanteles (= *Cotesia*) *ruficrus* (Haliday) (Braconidae)
Echthromorpha intricatoria (F.) (Ichneumonidae)
Euplectrus sp. (Eulophidae)
Macrocentrus rubromaculatus (Cameron) (Braconidae)
Pales nyctemeriana (Hudson) (Tachinidae)
Rogas sp. (Braconidae)
PUPAL PARASITOIDS
Ichneumon promissorius Erichson (Ichneumonidae)
Lissopimpla excelsa (Costa) (Ichneumonidae)
Netelia producta (Brullé) (Ichneumonidae)

Recoveries of *A. ruficrus* from *M. separata* were made soon after release, and the parasitoid quickly became established and spread from its release sites in the northern half of the North Island (Cumber *et al.* 1977). A full list of release sites and numbers is given by Cumber *et al.* (1977).

Evaluation

The only quantitative information on larval parasitism prior to release of the Pakistan strain is provided by Agnew (1974). He recorded a mean level of 36% parasitism of *M. separata* from maize, sweetcorn and pasture in the south of the North Island. The three main species were *A. ruficrus* (46%), *Euplectrus* sp. (23%) and *Pales nyctemeriana* (30%) (Hudson). Subsequent to its release in 1971/72, *A. ruficrus* was found to be well established on *M. separata*, with very high rates of larval parasitism (Cumber *et al.* 1977, Hill 1977, Hill *et al.* 1985, Hill 1988). The parasitism was almost exclusively caused by *A. ruficrus* (greater than 95%). Hyperparasitism of *A. ruficrus* by the pteromalid *Trichomalopsis* sp. was less than 5%.

Before release of the Pakistan strain, large areas of grain crops (mostly maize) and pasture were sprayed for control of *M. separata* (Hamblyn 1959, Kain *et al.* 1968). Following its establishment, chemical control is rarely necessary. *A. ruficrus* has been heralded as one of the outstanding examples of successful classical biological control in recent years (Simmonds & Bennett 1977) and estimates of its annual monetary benefits to New Zealand range from NZ$4.5-10 million (Hill 1977, Mohyuddin & Shah 1977, Simmonds & Bennett 1977).

While reduction in *M. separata* outbreaks has been substantial, they still occur (Hill & Atkins 1982, Hill 1988). Recent work has established that outbreak populations in maize are favoured by the presence of weeds in the crop (Hill & Allan 1986), while a study of the effects of *A. ruficrus* on food consumption by *M. separata* larvae (Hill 1986) has shown that it very significantly reduces food consumption. This effect raises the threshold *M. separata* larval density at which significant damage occurs. In maize crops, estimates of damaging threshold densities of *M. separata* before and after the introduction of the Pakistan strain of *A. ruficrus* are 240-360/m^2 and 400-530/m^2 (Hill 1988). Lack of evidence for obvious reductions in *M. separata* population levels following the successful biological control, plus the discovery of strong density dependent pupal parasitism (Hill 1988) has led to the suggestion that the feeding reduction caused by *A. ruficrus* may make a more important contribution to the biological control of *M. separata* than the ability of *A. ruficrus* to reduce *M. separata* abundance (Hill 1988).

Discussion of importation of noctuid egg parasitoids which will attack *M. separata* is given in Chapter 21.

Literature Cited

Agnew, F. (1974) The biology and ecology of two species of army-caterpillars, *Persectania aversa* Walker and *Pseudaletia separata* Walker in New Zealand. M.Sc. thesis, Victoria University of Wellington, New Zealand, 132 pp.

Clearwater, J.R. (1971) The role of the male produced pheromone in the reproduction behaviour of the southern armyworm *Pseudaletia separata* (Wlk). M.Sc. thesis, Massey University.

Cumber, R.A.; Allan, D.J.; Helmore, L. (1977) Introduction and successful establishment in New Zealand of further strains of *Apanteles ruficrus* Haliday (Hymenoptera: Braconidae) to combat *Pseudaletia separata* Walker (Lepidoptera: Noctuidae). *New Zealand journal of agricultural research* 20, 255-258.

Hamblyn, C.J. (1959) Army caterpillar damage on east coast hill country. *New Zealand journal of agriculture* 98, 329-333.

Hill, M.G. (1986) Effects of *Cotesia ruficrus* (Braconidae: Hymenoptera) parasitism and rearing density on *Mythimna separata* (Noctuidae: Lepidoptera) food consumption, and implications for biological control. *New Zealand journal of agricultural research* 29, 281-288.

Hill, M.G. (1988) Analysis of the biological control of *Mythimna separata* (Noctuidae: Lepidoptera) by *Apanteles ruficrus* (Braconidae: Hymenoptera) in New Zealand. *Journal of applied entomology* 25, 197-208.

Hill, M.G.; Allan, D.J. (1986) The effects of weeds on armyworm in maize. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 260-263.

Hill, M.G.; Atkins A.W. (1982) Effects of defoliation by cosmopolitan armyworm (*Mythimna separata* Walker) on maize yield. *New Zealand journal of agricultural research* 25, 251-254.

Hill, R.L. (1977) Parasite helps control army caterpillar. *New Zealand journal of agriculture* 134, 21-23.

Hill, R.L.; Cumber, R.A.; Allan, D.J. (1985) Parasitoids introduced to attack larvae of the Noctuidae (Lepidoptera) in New Zealand (1968-1978). DSIR Entomology Division report no. 5, 24 pp.

Kain, W.M.; Wallis, W.J.; Payne, E.O. (1968) Control of army caterpillar, *Pseudaletia separata*. *Proceedings of the 21st New Zealand Weed and Pest Control Conference*, 202-208.

Mohyuddin, A.I.; Shah, S. (1977) Biological control of *Mythimna separata* (Lep: Noctuidae) in New Zealand and its bearing on biological control strategy. *Entomophaga* 22, 331-333.

Sharma, H.C.; Davies, J.C. (1983) The oriental armyworm *Mythimna separata* (Walk.) distribution, biology and control: a literature review. *Centre for Overseas Pest Research, ODA Miscellaneous Report* 59, 1-24.

Simmonds, F.J.; Bennett, F.D. (1977) Biological control of agricultural pests. *Proceedings of the 15th International Congress of Entomology* 26, 464-472.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Valentine, E.W.; Walker, A.K. (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, (in press).

Nezara viridula (L.), green vegetable bug (Hemiptera: Pentatomidae)

P.J. CAMERON

Pest Status

Nezara viridula (L.) was first recorded in New Zealand in 1944 (Cumber 1949), and its subsequent spread throughout the North Island and to Marlborough and Nelson is described by Everett (1958). This insect is reported as a sporadic pest in the warmer areas of New Zealand, particularly Northland, Auckland and the Bay of Plenty. Early reports state that in Northland, *N. viridula* was a severe pest on almost every kind of vegetable as well as tamarillos and peaches (Everett 1958). This reflects the ability of the bugs to suck sap of most fruit, developing seed, stems and foliage. They puncture tissue and inject digestive fluid into the wound causing discolouration, pitting and shrivelling, as well as providing entry points for pathogens. The New Zealand literature (Allan 1976, Cumber 1949, Everett 1958) commonly records damage to beans, capsicums, corn, peas, tomatoes, passionfruit and tamarillos. Feeding also occurs on other vegetables including brassicas, potatoes, pumpkins and silver-beet. Adults shelter and overwinter on a variety of crop plants and weeds which provide sites from which reinfestation can occur. Plant damage from *N. viridula* has declined over the years (Cumber 1964) but remains sporadic. The current importance of this pest may depend on the incidence of susceptible crops. For example, large populations have occasionally been observed in soybeans (Cameron *et al.* 1986) and increased reports of damage to macadamia crops have paralleled the increasing interest in this crop (DSIR files).

All stages of *N. viridula* can be present from December to May (Allan 1976). The eggs are laid in rafts of 40-80 cemented to the underside of a leaf or in other sheltered positions, making them difficult to locate in the field. Eggs hatch in 10-20 days and the nymphs develop through five instars. The life cycle requires about 60 days during the most favourable summer conditions and allows the development of at least two generations (Cumber 1949).

Background

No indigenous parasitoids are known to attack *N. viridula*. Cumber (1964) recorded a 'resident species' of scelionid, *Trissolcus* (= *Microphanurus*) sp., from the eggs of five pentatomid species but showed experimentally and from field collections that this species did not parasitise *N. viridula*. Throughout its world distribution, other than areas to which it has spread this century, *N. viridula* has a range of natural enemies including the scelionids *Trissolcus* spp. and the tachinids *Trichopoda* spp. (Thompson 1944). Several biological control programmes have introduced parasitoids originating from the West Indies, Egypt, Italy, Pakistan and Japan, to the South Pacific, Australia and Hawaii, and there has been considerable redistribution of parasitoids to countries including New Zealand.

In Australia there have been several phases of importation and redistribution of *Trissolcus basalis* (Wollaston). The original importations from Egypt to Western Australia in 1933 were redistributed within Australia until about 1945 (Wilson 1960). Further strains were imported from 1956 to 1963 (Ratcliffe 1965), largely to improve control in inland areas. In 1984 *T. basalis* was imported from the U.S.A., Brazil and South Africa to improve control in south eastern Queensland, particularly on soybeans (J. Turner pers. comm.). Waterhouse & Norris (1987) concluded that the varying success and distribution patterns of the Australian introductions support the existence of several different strains of *T. basalis*.

Predation has not been recorded in New Zealand, although spiders and a predaceous nabid have been noted in Japan (Hokyo & Kiritani 1963). A bacterial pathogen '*Diplococcus*' has been reported from laboratory cultures (Harris & Todd 1981). Neither predators nor pathogens have been used for biological control.

There are few specific recommendations for chemical control of *N. viridula* in New Zealand. In commercial crops of tomatoes, beans and brassicas, regular spraying for Lepidoptera will give some control. Destruction of old crop residues and weeds may reduce overwintering populations, but reinfestation of crops may also result from adults flying considerable distances.

Importations, Releases and Recoveries

Trissolcus (= *Asolcus*) *basalis* (Wollaston) (Hymenoptera: Scelionidae)

The importation of *T. basalis* from Australia in January 1949 is described by Cumber (1951). From a single importation of 200-300 eggs, more than 40,000 parasitoids were reared and released in February and March 1949 at seven sites in Northland, and one site each at New Plymouth and Opotiki. Redistribution was carried out in 1951 to Onehunga, Nelson, and a further Northland site at Dargaville (Cumber 1953). Redistribution was continued to 1959, through requests from private individuals, and also by the Department of Agriculture (DSIR files). Recorded liberations from 1954 to 1957 extended the range to include Waiheke and Great Barrier Islands, Coromandel, Tauranga, Gisborne, Hastings, Te Awamutu, Manawatu and Nelson. By 1964 the parasitoid had been released in all areas where *N. viridula* was abundant (Cumber 1964).

Recoveries were made soon after releases at Paihia (Northland) in 1950 and Onehunga in 1951 (Cumber 1953), and the parasitoid persisted at these sites (Everett 1958). In Nelson, *T. basalis* was reared from *N. viridula* eggs in 1960 (specimens in the New Zealand Arthropod Collection). Cumber (DSIR files) considered that by 1967 the parasitoid was present throughout the range of its host. *T. basalis* was also shown to be capable of parasitising other pentatomid species (Cumber 1964).

Trichopoda pennipes (F.) (Diptera: Tachinidae)

A total of 235 pupae of *T. pennipes* was received from Hawaii in January and February, 1965. The original material was obtained from Florida in 1963 and established in Hawaii in 1964 (Davis & Krauss 1964, 1965). The rearing and release of this parasitoid as described here is based on a 1967 report by R.A. Cumber (DSIR files), which indicates that *T. pennipes* was reared successfully from 1965 to February 1967. Rearing methods were based on those of Davis (1964) using field collected *N. viridula* adults as hosts. The development period for a generation of *T. pennipes* was five to six weeks in Auckland summer insectary conditions of 15-27°C. The success rate of parasitism was 11% when older overwintering hosts predominated, and increased to 57% in February when new season hosts were used. Up to five parasitoid eggs were commonly laid on one host without reducing successful emergence of the single surviving parasitoid. The success rate of parasitoid larval emergence decreased as the number of eggs per host increased from five to 13, and no larvae emerged from hosts with more than 13 eggs. The frequency distribution of egg density per host in February rearing was similar to the distribution of *T. pennipes* eggs found by Hokkanen (1983) from field collected *N. viridula* in Florida.

Three releases were made at Paihia during the periods February 1965, February-March 1966 and December-January 1967. These comprised 3,730 parasitised *N. viridula* adults and 80 adult *T. pennipes* (R.A. Cumber, DSIR files). The release site included native vegetation, a cultivated area containing suitable host plants for *N. viridula*, and high populations of host insects which were augmented by the liberation of further adults. A factor reported to limit

the success of *T. pennipes* released as adults was predation of the flies by *Vespula germanica* (F.).

There were no recoveries from the first two releases of *T. pennipes*, but in May 1967 Cumber (DSIR files) noted four individual *N. viridula* each with a single egg attached. This indicated the survival of at least one generation but no further recoveries have been reported.

Evaluation

The distribution of *Trissolcus basalis* is not specifically documented in the literature or subsequent records (DSIR files). However, the early establishment of this parasitoid and records of its persistence at widely disparate sites indicate that by 1967 *T. basalis* was present in all major areas affected by *N. viridula*. Evaluation of the impact of *T. basalis* is also hindered by the difficulty in locating host egg masses.

A survey was carried out in March 1985 (Cameron unpublished) to evaluate the current status of *T. basalis*. Single egg masses were glued to cards and placed at 16 sites (10/site) in Northland and Auckland. *T. basalis* was recovered from all the main areas surveyed, i.e. five Northland areas: Kaitaia, Kaikohe, Kerikeri, Rawene, Dargaville; and three Auckland areas: Helensville, Mt Albert and Pukekohe. Of four sites where no egg masses were parasitised, all but one had a nearby site within 5 km where *T. basalis* was present. All the eggs were exposed for one week during which 28% of the masses were parasitised. These results, together with the earlier literature (e.g. Cumber 1964), indicate that variability in damage caused by *N. viridula* is unlikely to be caused by the absence of *T. basalis* from particular areas.

T. basalis has been considered to give effective control of *N. viridula* in some locations, and the degree of control may have increased for several years following introductions. At Paihia, Cumber (1953) recorded 90% of egg masses parasitised and considered that a 'high measure of control' had been achieved. A reduction in overwintering adult populations was said to delay the spring and early summer population increases. By 1964 the severity of plant damage by *N. viridula* was considered to have declined (Cumber 1964). Little is known concerning the variability in effectiveness of *T. basalis* in different areas of New Zealand. Present information is insufficient to determine if regional problems with *N. viridula* are related to low levels of parasitism.

Conclusions

The decline of *N. viridula* populations following the introduction of *T. basalis* in New Zealand parallels that achieved in parts of Australia. The importation of this parasitoid from Egypt in 1933 produced a reduction in pest status of *N. viridula* in most Australian States (Wilson 1960). Control was less satisfactory in inland New South Wales where relatively cold winters were considered to reduce overwinter survival of the parasitoid. The material introduced into New Zealand in 1949 was obtained from the CSIRO at Canberra and presumably originated from naturalised Australian strains which may have been susceptible to cooler winters. Ratcliffe (1965) reported improved control in inland areas following the introduction of further strains of *T. basalis* from 1956 to 1963. Waterhouse & Norris (1987) attributed the population decline of *N. viridula* to these new releases, and recommended the importation of further strains where improved control is sought.

Trichopoda pennipes failed to establish in New Zealand despite successful rearing under natural insectary conditions and considerable releases. As it has also failed to establish in Australia and several South Pacific Islands (Waterhouse & Norris 1987), it is unlikely to be reintroduced. In Hawaii, where two *Trichopoda* spp. are established, *T. pilipes* (F.), introduced from the West Indies, has achieved higher rates of parasitism than *T. pennipes* from Florida (Davis & Krauss 1965).

Since the decline in pest status of *N. viridula* in New Zealand (Cumber 1964), sporadic outbreaks are confined to areas of warm climate and susceptible crops. The contribution of *Trissolcus basalis* to this decline is unknown, therefore the major requirement for future work is an evaluation of the parasitoid. It is possible that the *T. basalis* population in New Zealand has limited adaptability as a result of the original introduction of few individuals of one strain. The importation of further strains from Australia has been considered, but the limited economic status of *N. viridula* has reduced the priority of this project. It is likely that the reimportation of *T. basalis* from Australia would extend its range of effectiveness in New Zealand.

Acknowledgements

The section on *Trichopoda pennipes* is based on a report by R.A. Cumber (DSIR files) describing the work he and D.J. Allan carried out from 1965 to 1967.

Literature Cited

Allan, D.J. (1976) Green vegetable bug, *Nezara viridula* (Linnaeus), life cycle. *DSIR information series* 105/17.

Cameron, P.J.; Allan, D.J.; Walker, G.P. (1986) Insect pests and crop damage in soybeans. *New Zealand journal of agricultural research* 29, 93-100.

Cumber, R.A. (1949) The green vegetable bug *Nezara viridula*. *New Zealand journal of agriculture* 79, 563-564.

Cumber, R.A. (1951) The introduction into New Zealand of *Microphanurus basalis* Woll. (Scelionidae: Hym.), egg-parasite of the green vegetable bug, *Nezara viridula* L. (Pentatomidae). *New Zealand journal of science and technology* B32, 30-37.

Cumber, R.A. (1953) The establishment in New Zealand of *Microphanurus basalis* Woll. (Scelionidae: Hym.), egg-parasite of the green vegetable bug, *Nezara viridula* L. (Pentatomidae). *New Zealand journal of science and technology* B34, 267-269.

Cumber, R.A. (1964) The egg parasite complex (Scelionidae: Hymenoptera) of shield bugs (Pentatomidae, Acanthosomidae: Heteroptera) in New Zealand. *New Zealand journal of science* 7, 536-554.

Davis, C.J. (1964) The introduction, propagation, liberation and establishment of parasites to control *Nezara viridula* variety *smaragdula* (Fabricius) in Hawaii (Heteroptera: Pentatomidae). *Proceedings of the Hawaiian Entomological Society* 18, 369-375.

Davis, C.J.; Krauss, N.L.H. (1964) Recent introductions for biological control in Hawaii – IX. *Proceedings of the Hawaiian Entomological Society* 18, 391-397.

Davis, C.J.; Krauss, N.L.H. (1965) Recent introductions for biological control in Hawaii – X. *Proceedings of the Hawaiian Entomological Society* 19, 87-90.

DSIR, Entomology Division, file BC1/4.

Everett, P. (1958) The green vegetable bug. *New Zealand journal of agriculture* 97, 469 & 471-472.

Harris, V.E.; Todd, J.W. (1981) Rearing the southern green stink bug, *Nezara viridula*, with relevant aspects of its biology. *Journal of the Georgia Entomological Society* 16, 203-211.

Hokkanen, H. (1983) Interspecific homeostasis, pest problems, and the principles of classical biological pest control. Ph.D. thesis, Cornell University, Ithaca, N.Y., 157 pp.

Hokyo, N.; Kiritani, K. (1963) Two species of egg parasites as contemporaneous mortality factors in the egg population of the southern green stink bug, *Nezara viridula*. *Japanese journal of applied entomology and zoology* 7, 214-226.

Ratcliffe, F.N. (1965) Biological control. *Australian journal of science* 28, 237-240.

Thompson, W.R. (1944) A catalogue of the parasites and predators of insect pests. Section 1; Parasite host catalogue: Part 7; Parasites of the Hemiptera. Imperial Agricultural Bureau, Belleville, Ontario, Canada, 149 pp.

Waterhouse, D.F.; Norris, K.R. (1987) Biological control: Pacific prospects. ASCIAR, Inkata Press, Melbourne. 454 pp.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Noctuidae, noctuid moths (Lepidoptera)

P.J. CAMERON and D.J. ALLAN

Pest Status

The Noctuidae have been considered as a pest group in planning for biological control programmes using parasitoids in the family Trichogrammatidae, which parasitise the egg stage. The pests in this group are primarily *Helicoverpa armigera* (Hübner), *Chrysodeixis eriosoma* (Doubleday), *Agrotis ipsilon* (Hufnagel) and *Mythimna separata* (Walker). Their pest status is described in Chapters 10, 12, 14, and 19 which detail the biological control programmes directed specifically at each pest. *Persectania aversa* (Walker) (southern armyworm), is an endemic species which attacks grasses and graminaceous seed crops (Chapman 1984), but no biological control programmes have been aimed against this pest. The other noctuids are geographically cosmopolitan in distribution, and altogether occur through a wide range of modified habitats in New Zealand including pasture, field crops, gardens and weedy areas.

Background

Information on the indigenous parasitoids specific to particular noctuid larvae is provided in chapters on the individual pests. A range of more generalist species has been reared from several noctuids. Valentine (1967) lists these, and notes *Macrocentrus rubromaculata* (Cameron) from three host species, and *Echthromorpha intricatoria* (F.) and *Ichneumon* (= *Pterocormus*) *promissorius* (Erichson) from *H. armigera* and one other species. It is probable that these parasitoids and others, e.g. *Netelia producta* (Brullé), have a wider host range similar to that recorded for the same species in Australia (Room 1979). The impact of these parasitoids on noctuid populations is unknown.

Two pentatomid predators commonly found in association with larvae of noctuids on field crops are *Cermatulus nasalis* (Westwood) and *Oechalia schellembergii* Guérin-Méneville, and these probably feed on all the pest larvae noted above (Valentine 1967, Cameron unpublished).

Two indigenous Trichogrammatidae have been reared from noctuid eggs in New Zealand. R.A. Cumber collected a *Trichogrammatoidea* sp. in 1974 from Paihia (Northland) and Auckland, and recorded 60-100% parasitism from *H. armigera* eggs and 80-100% from *Chrysodeixis eriosoma* eggs (DSIR files). This parasitoid was reared by Cumber in the laboratory on eggs of the four main Noctuidae noted above, as well as *Ctenoplusia albostriata* (Bremer & Grey), *Chrysodeixis argentifera* Guenée, *Dasypodia selenophora* Guenée, *Graphania mutans* (Walker) and *G. ustistriga* (Walker). Other acceptable laboratory hosts were *Achroia grisella* (F.), *Cydia pomonella* (L.) and occasionally *Danaus plexippus* (L.).

A survey for noctuid parasitoids by R.L. Hill and D.J. Allan (Entomology Division DSIR 1976) showed wide variability in the rates of egg parasitism, but particularly noted higher rates in northern areas. North of Whangarei in Northland, they recorded 81% parasitism from *H. armigera* eggs, and 54% from *Chrysodeixis eriosoma*. Recent identification of some of these specimens by A. Polaszek (CABI Institute of Entomology) confirmed the presence of *Trichogrammatoidea bactrae* Nagaraja, and a second parasitoid, *Trichogramma* (*Trichogrammanza*) *funiculatum* Carver. Both parasitoids were reared from *H. armigera* and *C. eriosoma*, but *T. funiculatum* was less common.

Pathogens recorded in New Zealand from pest noctuids are listed in Table 21.1. Hill *et al.* (1985) provided quantitative estimates of disease from rearing field collected larvae. They generally attributed low rates of disease to these organisms, except for one sample of *M. separata* in which 50% were infected with a *Nosema* sp. *Helicoverpa* nuclear polyhedrosis virus is uncommon in the field, appearing in less than 1% of larvae reared from field crops from 1981 to 1988 (Cameron unpublished).

Table 21.1 Pathogens associated with pest Noctuidae in New Zealand

Noctuid species	Pathogen	Source
Agrotis ipsilon	*Vavraia oncoperae* (Microspora)	Malone *et al.* 1987
Chrysodeixis eriosoma	Cytoplasmic polyhedrosis virus	Longworth 1981
Helicoverpa armigera	Nuclear polyhedrosis virus	Hill *et al.* 1985
Mythimna separata	Nuclear polyhedrosis virus	Hill *et al.* 1985
	Metarhizium anisopliae (Hyphomycetes)	Hill *et al.* 1985
	Beauveria densa (Hyphomycetes)	Hill *et al.* 1985
	Nosema sp. (Microspora)	Hill *et al.* 1985
	Small-spored microsporidian	P.J. Wigley (pers. comm.)

Commercial preparations of viruses such as 'Elcar' have not been registered for use in New Zealand. *Bacillus thuringiensis* Berliner is registered for use against *H. armigera* and *C. eriosoma* in glasshouses but is not used against noctuids in outdoor crops.

Importations, Releases and Recoveries

Four species of *Trichogramma* were imported in six shipments during 1974 from cultures held by Dr S. Nagarkatti at the CIBC Indian Station in Bangalore. These cultures originated from various localities (Table 21.2) and were reared at Bangalore on *Corcyra cephalonica* (Stainton). The species imported as '*T. australicum*' is referred to by Pinto *et al.* (1982) as *T. chilonus* Ishii. In addition, *T. evanescens* is qualified *sens. lat.* because Pintureau & Voegelé (1980) have shown that in Europe it includes a second species, *T. maidis* Pintureau & Voegelé. The material imported into New Zealand has not been re-examined to determine its current taxonomic status, but voucher specimens have been deposited in the New Zealand Arthropod Collection using the names in Table 21.2.

Frozen eggs of all the four main noctuid pests were used in mass rearing these species for release. All four *Trichogramma* spp. were also shown to develop satisfactorily on *Graphania mutans*, *Ctenoplusia albostriata* and *Galleria mellonella* (L.). *T. dendrolimi* Matsumura and *T. evanescens* (= *euproctidis*) were also reared on *Phthorimaea operculella* (Zeller) and *Graphania ustistriga*. Each of the four parasitoid species was released at approximately 12

Table 21.2 *Trichogramma* species imported from the CIBC Indian Station at Bangalore during 1974, and released in 1974 and 1975 (D.J. Allan, DSIR files)

Species	Origin of culture	Number received	Number released
T. chilonus	Taiwan	20,000	530,000 (+ 4,000 to Cook Is.)
T. dendrolimi	Japan	10,000	193,000 (+ 2,000 to Cook Is.)
T. evanescens (='*T. euproctidis*')	Germany	10,000	250,000
T. evanescens (sens. lat.)	Poland	40,000	86,000 (+ 4,000 to Cook Is.)

localities from Waipu (north of Auckland) to Pukekohe (south of Auckland). Releases commenced in February 1974 and continued until May 1975, except for '*T. euproctidis*' which was released only in 1974. The total numbers released are given in Table 21.2 and full details are available in an unpublished report by D.J. Allan (DSIR files). In addition, three species were shipped and released at Rarotonga in the Cook Islands in 1974 (DSIR files).

Recovery surveys, including the use of trap eggs placed in the field for three days, were carried out one month after releases ceased. These did not detect parasitism by any of the introduced species.

Evaluation

Subsequent surveys for establishment have not recovered the introduced *Trichogramma* spp. In 1976, naturally occurring eggs of *H. armigera* and *C. eriosoma* were sampled over a wide area of Northland and Auckland at sites described by Hill *et al.* (1985). This survey recovered only the native Trichogrammatidae. Intensive sampling of noctuid eggs in tomatoes in the Auckland area (P.J. Cameron unpublished) have confirmed the failure to establish the introduced *Trichogramma* spp.

Conclusions

The *Trichogramma* species introduced into New Zealand represent the species most commonly used in biological control programmes overseas, i.e. *T. chilonus* in India (Manjunath *et al.* in press), *T. dendrolimi* in China (King *et al.* 1985) and *T. evanescens* (sens. lat.) in Europe (Hassan 1982). However, another species, *T. pretiosum* Riley is widely used in field crops in North America (King *et al.* 1985, Oatman *et al.* 1983) and has been released in Australia (Michael *et al.* 1984), but was not imported into New Zealand. The widespread geographic distribution of this species (Pinto *et al.* 1986) indicates its ability to survive in a range of climates, and suggests that some strains could persist in New Zealand. However, if new species are to be imported from continental field cropping areas with typically hot summers, their ability to control noctuids in cooler New Zealand climatic conditions must also be considered. For example, Pak & Oatman (1982) measured the highest intrinsic rate of increase for *T. pretiosum* (from southern California) at 25-30°C, which is considerably higher than average New Zealand summer temperatures.

A major factor in the possible future use of *Trichogramma* in augmentative release programmes in New Zealand is the cost of labour involved in rearing programmes. King *et al.* (1986) indicate that where insecticides represent the major control practice *Heliothis* manage-

ment with *Trichogramma* is not feasible. However, mass release programmes have been used successfully in small scale cropping systems to replace insecticides (Bigler 1986). Successful adaptation of overseas technology at a scale suitable and economic for New Zealand conditions will play a large role in determining if *Trichogramma* could be used in augmentative releases against Noctuidae, or if classical inoculative releases are the only option. Either approach should be preceded by an evaluation of the host relationships of the existing Trichogrammatidae.

Acknowledgements

The 1974 records for *Trichogrammatoidea* sp. parasitism and host range are based on the unpublished data of R.A. Cumber. R.L. Hill also provided access to unpublished data. A. Polaszek, CABI Institute of Entomology identified *T. bactrae* and *T. funiculatum*.

Literature Cited

Bigler, F. (1986) Mass production of *Trichogramma maidis* Pint. & Voeg. and its field application against *Ostrinia nubilalis* Hbn. in Switzerland. *Journal of applied entomology* 101, 23-29.

Chapman, R.B. (1984) Pasture pests. Pp. 119-142 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

DSIR, Entomology Division, f' es BC 1/4.

Entomology Division DSIR (1976) Annual report, 21-23.

Hassan, S.A. (1982) Mass-production and utilisation of *Trichogramma*: 3. Results of some research projects related to the practical use in the Federal Republic of Germany. *Les Trichogrammes*, Colloq. INRA (France) No. 9, 213-218.

Hill, R.L.; Cumber, R.A.; Allan, D.J. (1985) Parasitoids introduced to attack larvae of the Noctuidae (Lepidoptera), and their establishment in New Zealand (1968-78). DSIR Entomology Division report no. 5. 24 pp.

King, E.G.; Bull, D.L.; Bouse, L.F.; Phillips, J.R. (1985) Biological control of *Heliothis* spp. in cotton by augmentative releases of *Trichogramma*. *The southwestern entomologist*, supplement 8, 1-10.

Longworth, J.L. (1981) The replication of a cytoplasmic polyhedrosis virus from *Chrysodeixis eriosoma* (Lepidoptera: Noctuidae) in *Spodoptera frugiperda* cells. *Journal of invertebrate pathology* 37, 54-61.

Malone, L.A.; Wigley, P.J.; Dhana, S.D. (1987) Identity of a microsporidium from three New Zealand pasture insects, *Costelytra zealandica* (Coleoptera, Scarabaeidae), *Wiseana* spp. (Lepidoptera, Hepialidae) and *Listronotus bonariensis* (Coleoptera, Curculionidae). *Journal of invertebrate pathology* 49, 135-144.

Manjunath, T.M.; Bhatnagar, V.S.; Pawar, C.S.; Sithanantham, S. (in press) Economic importance of *Heliothis* spp. in India and an assessment of their natural enemies and host plants. In Jackson, R.D.; King, E.G. (eds), Proceedings of workshop: Biological control of *Heliothis*, Amerind Press, New Delhi.

Michael, P.J.; Woods, W.; Lawrence, P.J.; Fisher, W. (1984) Introduced parasites for the control of Australian noctuid pests. Pp. 294-303 in Bailey, P.T.; Swincer, D.E. (eds), *Proceedings of the 4th Australian Applied Entomological Research Conference*, Adelaide, Australia.

Oatman, E.R.; Platner, G.R.; Wyman, J.A.; van Steenwyk, R.A.; Johnson, M.W.; Browning, H.W. (1983) Parasitization of lepidopterous pests on fresh market tomatoes in Southern California. *Journal of economic entomology* 76, 452-455.

Pak, G.A.; Oatman, E.R. (1982) Comparative life table, behaviour and competition studies of *Trichogramma brevicapillum* and *T. pretiosum*. *Entomologia experimentalis et applicata* 32, 68-79.

Pinto, J.D.; Oatman, E.R.; Platner, G.R. (1982) *Trichogramma australicum* Girault (Hymenoptera: Trichogrammatidae): redescription releases of *Trichogramma*. *The southwestern entomologist*, supplement 8, 1-10.

Pinto, J.D.; Oatman, E.R.; Platner, G.R. (1986) *Trichogramma pretiosum* and a new cryptic species occurring sympatrically in southwestern North America (Hymenoptera: Trichogrammatidae). *Annals of the Entomological Society of North America* 79, 1019-1028.

Pintureau, B.; Voegelé, J. (1980) Une nouvelle espèce proche de *Trichogramma evanescens*: *T. maidis* (Hym.: Trichogrammatoidae). *Entomophaga* 25, 431-440.

Room, P.M. (1979) Parasites and predators of *Heliothis* spp. (Lepidoptera: Noctuidae) on cotton in the Namoi Valley, New South Wales. *Journal of the Australian Entomological Society* 18, 223-228.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Phthorimaea operculella (Zeller), potato tuber moth (Lepidoptera: Gelechiidae)

A.M. FERGUSON

Pest Status

Of the lepidopterous larvae found damaging potato *Solanum* spp. tubers or foliage in New Zealand, the most common species is *Phthorimaea* (= *Gnorimoschema*) *operculella* (Zeller). The other gelechiid known to cause potato damage here is the tomato stem borer *Symmetrischema* (= *Scrobipalpa*) (= *Gnorimoschema*) *plaesiosema* (Turner) which infests mainly the stems and tubers (Anonymous 1982, 1986). Overseas, potatoes are attacked by the tomato fruit moth *Scrobipalpula* (= *Phthorimaea*) (= *Gnorimoschema*) *absoluta* (Meyrick), mostly in foliage (Anonymous 1979, Valencia 1985) and *Scrobipalpopsis solanivora* Povolný which predominantly attacks growing and stored tubers until they are completely destroyed (Povolný 1973). The two latter species appear to be confined to South and Central America respectively, but *Symmetrischema plaesiosema* is present in North and South America (Valencia 1985), Australia (Morgan 1931) and New Zealand (Muggeridge 1932), although it has never been observed on potatoes at Pukekohe, New Zealand (M.A. Wood pers. comm.). In addition, Australia has 54 species of Gelechiidae, including 13 species of *Scrobipalpa*, e.g. *S. heliopa* (Lower) on tobacco (Common 1970) but there has been no survey undertaken to ascertain their presence in New Zealand.

Potato tuber moth, *P. operculella*, (PTM) also has the common names of 'potato tuberworm', 'potato moth', and 'tobacco leaf miner' (Meisner *et al.* 1974), and was present in New Zealand prior to 1854 (Berthon 1855). The method of entry is uncertain but may have been from infested tubers (Kirk 1894). Its establishment and spread in New Zealand is not surprising because PTM is cosmopolitan in warm temperate, sub-tropical and tropical climates (Lloyd 1972) although it is absent from West Africa and parts of Asia (Haines 1977). This insect can breed readily on stored potato tubers which has facilitated its worldwide spread (Flanders & Oatman 1987).

PTM is of pest status because larvae mine plant foliage and stems, leaf petioles, fruits and potato tubers (Izhevskiy 1985). Plant and tuber damage is especially prevalent in hot, dry summers (Muggeridge 1936). Stored tubers can be attacked throughout the year (Foot 1975) and may be repeatedly attacked until rendered unfit for human consumption or use as seed (Helson 1974). The life history of this pest in New Zealand is described by Foot (1975, 1979). Host plants are mainly solanaceous and include potatoes (the preferred plant (Meisner *et al.* 1974)), tobacco, cape gooseberry *Physalis peruviana* L., capsicum, tamarillo leaves *Cyphomandra betacea* Sendtner (rarely) and the native poroporo *Solanum aviculare* G. Forster (Foot 1976c). The foliage of poroporo may be severely damaged from December until late February when transplants are small and low to the ground (N.A. Martin pers. comm.) but uncultivated poroporo is rarely attacked. The nightshade *Solanum* spp. weed complex are also host plants (Helson 1974). Besides attacking the growing plants, PTM can damage stored tomato and egg plant fruits (Haines 1977). Sugar beet has been recorded as a host in Europe (Haines 1977) but the insect responsible may have been the sugar beet moth *Scrobipalpa ocellatella* (Boyd).

The most economically serious damage is caused by potato tuber infestations. Infestation levels at harvest in Canterbury in the South Island may approach 80% in unsprayed, unirrigated crops after hot summers (J.W. Marshall pers. comm.). Sprayed, irrigated crops at Pukekohe in the North Island, are 8-20% infested at harvest while unsprayed plants can

have 11-86% damage (Bedi 1974, Foot 1974a, 1974b, 1976b, 1976c). These levels can be compared with the 30-70% storage losses in many equatorial regions (Raman & Palacios 1982).

Background

PTM larvae are advantaged when in the tuber because they are relatively protected from parasitoids (Chaudhary *et al.* 1983, Cock 1985, Graf 1917) and insecticides (Flanders & Oatman 1982, Foot 1979). Tuber infestation must therefore be reduced by the implementation of both cultural techniques and the suppression of the foliar population by biological and insecticidal methods. Furthermore, larvae must be controlled on the aerial portions of the plant to prevent both yield loss (Bald & Helson 1944) and the wilt and ultimate death of the host plant especially when it is in the seedling stage (Oatman & Platner 1974, M.A. Wood pers. comm.). The ability of PTM to produce six to eight generations in a year in Pukekohe (Foot 1975), developing in all portions of wild and cultivated solanaceous plants, with pupation in the soil or in leafy ground litter, exacerbate the problem of control. Immigration, especially from volunteer plants, also contributes to the problem of control both in the field and in stored tubers (Haines 1977). Because of the overlap of generations, the number of suitable insecticides is limited to those with larvicidal and ovicidal activity, and with reasonably long biologically-active residues (Foot 1976a). Insecticide resistance in PTM has been reported overseas (Georghiou 1981, Haines 1977, Ramirez *et al.* 1973). Additional difficulty with control will be experienced if this phenomenon becomes widespread. Resistance to a granulosis virus has also been reported and investigated in Australia (Briese 1982).

At Pukekohe (37°15′S), in the Auckland Province, an insecticide is applied for PTM control every seven to ten days from mid-December until March resulting in a schedule of six to eight applications to a potato crop each season (Foot 1974a). In contrast, crops south of Nelson (41°4′S), South Island, are rarely sprayed because this pest is an infrequent problem.

Tubers can be protected prior to storage by spraying and dusting (Goldson & Emberson 1985, Passlow & Rossiter 1973) or with in-store fumigation (Anonymous 1987, Helson 1942) or irradiation (Thomas *et al.* 1980). The disadvantages of such measures can be the reduction or destruction of the parasitoid population, consumer resistance e.g. to irradiation or taint or insecticidal residues (Haines 1977) and/or a deleterious effect on seed tuber quality (Anonymous 1987).

In New Zealand, the following cultural steps are recommended, in concert with insecticides and/or parasitoids, to reduce tuber infestation in the field: the use of less susceptible (Foot 1976c) or resistant (Huaman 1987) plants, e.g. cv. parda pastusa (Valencia 1985), wider row spacings, crop rotation (Haines 1977), field cleanliness (Goldson & Emberson 1985) remoulding ridges, chemical defoliation, re-grading 7-14 days after the initial grading, sowing uninfested seed pieces, harvesting at maturity (Valencia 1985) immediately following defoliation (Anonymous 1986). Irrigation (Shelton & Wyman 1979a) and an increase in the depth of sowing (Foot 1974b, 1976b, 1979) are particularly important practices. Cultural techniques for stored tubers include: covering bags or boxes of uninfested tubers and removing them to a clean moth-proof store as soon as practible (Anonymous 1986), removing nearby host plants, burning, dumping or covering infested tubers, the utilisation of repellents e.g. *Lantana* sp. (Anonymous 1982) and storing at a reduced temperature (Sankaran & Girling 1980).

The pheromone of tuber moth has been discovered (Fouda *et al.* 1975, Persoons *et al.* 1976) and refined. It has potential in water traps to monitor the presence and density of adult moths in the field (Shelton & Wyman 1979b, Valencia 1985), for field control by mating disruption (Anonymous 1987) and for PTM control in stores (Thal 1979). Autocidal control by sterilization has been reported (Haines 1977, Nabi & Harrison 1984) but has yet to become commercially acceptable.

Predation (Shelton *et al.* 1981, Springett & Matthiessen 1975, Valentine 1967), granulosis viruses (Matthiessen *et al.* 1978), fungi e.g. *Beauveria* sp. (J.D. Fletcher pers. comm.), bacteria (Amonkar *et al.* 1979, Anonymous 1987), and nematodes (Lloyd 1972) may be important biological mortality factors in the reduction of PTM populations in specific geographical areas. The granulosis viruses, predators, and their inter-relationships with parasitoids, have not yet been studied. In New Zealand, a granulosis virus and bacteria have been reported (Foot 1979, S.L. Goldson pers. comm.) but these appear to have only a minor role in population regulation in the field.

Although none of these treatments alone provides complete control, it is possible to select several techniques which may then be combined into an integrated programme of control (Raman & Booth 1983). Such programmes are currently being evaluated under the auspices of the International Potato Center, Lima, Peru.

Initial attempts at PTM control with parasitoids began in 1918 and 1920-21 when the braconid *Bracon* (= *Microbracon*) *gelechiae* Ashmead was imported into France, Cyprus and Malta from the U.S.A. There are conflicting reports about its establishment (Greathead 1976, Clausen 1978). Between 1943 and 1949 the Californian Station of the CIBC, in partnership with Australia, was active in the collection and shipment of parasitoids from North America. However, the focus of collection altered when Lloyd (1972) again suggested, as had Picard (1912), that the origin of the host was temperate and sub-tropical areas around the Andes Mountains in South America. Subsequent investigations in northern Argentina and southern Brazil in 1963-64 yielded a number of different parasitoids which were cultured by CIBC at the University of California and sent to participant Commonwealth countries (Lloyd 1972). Upon the closure of this station, most of the colonies were transferred to the CIBC Indian Station which enabled the continuation of the policy of rearing parasitoids for export until at least 1973 (DSIR files). As a result, a unique situation has arisen where more than 23 countries have imported about 30 species of parasitoids up until 1985. In addition, some countries have made releases of *Trichogramma* spp. against both PTM (Sankaran & Girling 1980) and *Scrobipalpula absoluta* (Bennett 1984) but with only limited success. A review of the parasitoids imported into different countries and their subsequent performance against PTM, is contained in Clausen (1978), Sankaran & Girling (1980) and Izhevskiy (1985).

Importations, Releases and Recoveries

The first introduction of PTM parasitoids into New Zealand was undertaken by the Cawthron Institute when in March, 1949, a permit was obtained to import one shipment of *Copidosoma koehleri* Blanchard, *Bracon gelechiae* and *Chelonus* (= *Microchelonus*) *phthorimaea* Gahan from Australia. The numbers involved are not recorded in DSIR files. Sankaran & Girling (1980) point out that in 1946 Australia imported *Copidosoma desantisi* Annecke & Mynhardt, not *C. koehleri*, so it is likely that this was the species introduced into New Zealand and released at Nelson after laboratory emergence (DSIR files). In 1964, five shipments of low numbers of four species were imported from Fontana, California (Table 22.1) but records do not indicate if releases were made. A second importation from Australia was made in 1966 but few adults emerged (Table 22.2).

Also in 1966, there began a series of importations from the CIBC Indian Station which lasted until 1970. The parasitoids and numbers involved are summarised in Table 22.3 following the nomenclature of Sankaran & Girling (1980). From January until April 1966, *C. koehleri* (approx. number imported 185,500), *Copidosoma* sp. (70,000), *Chelonus* (= *Microchelonus*) *curvimaculatus* Cameron (2,000) and *Orgilus lepidus* Muesebeck (17,000+?) were imported in 22 shipments. From November 1966, until March 1967, these same parasitoids, except *C. curvimaculatus* and *Copidosoma* sp., were re-introduced in 20 consignments. Six additional species were imported at that time (Table 22.3, I). All species were

Table 22.1 Parasitoids imported from CIBC Station, Fontana, California, to Nelson, New Zealand, 1964. All in larval hosts for insectary rearing. No record of releases.

Parasitoid	Approx. no. in each shipment	Date of arrival	Condition
HYMENOPTERA : BRACONIDAE			
Agathis sp.			
	100	2 December	good
	50	8 December	good
Apanteles ?subandinus Blanchard			
	50	15 July	good
	50	23 July	poor
	50	30 July	poor
ICHNEUMONIDAE			
Campoplex haywardi Blanchard			
	50	15 July	good
	50	23 July	mediocre
	50	30 July	poor
ENCYRTIDAE			
Copidosoma koehleri Blanchard			
	2,500	15 July	good
	3,000	23 July	good
	3,000	30 July	good

released directly, in varying numbers, at Nelson, Lincoln (includes Oamaru, because the exact region was not always clear in DSIR files), and at Palmerston North. All species released at Lincoln were also released at Oamaru except for *Orgilus parcus* Turner. A few *O. lepidus*, *C. koehleri* and *Agathis unicolor* Schrottky were retained for laboratory culture at Lincoln. In addition, *O. lepidus* was cultured at Nelson.

In January 1968, *C. koehleri* was liberated in large numbers at Lincoln and Oamaru from two shipments (Table 22.3, II). From November 1969, until April 1970, there were eight consignments of parasitoids of the same species as in 1966/1966-67, with four additional species: *O. parcus*, *Eriborus trochanteratus* Morley, *Diadegma turcator* Aubert, and *B. gelechiae*. A small number of each of the 1969-70 species except *A. unicolor*, *Apanteles scutellaris* Muesebeck and *Chelonus curvimaculatus* were retained at Nelson for laboratory culture. A limited number were bred and a few released there before the laboratory host population became infected with a granulosis virus which caused the termination of the multiplication programme. No parasitoids were released in the North Island.

Table 22.2 Parasitoids imported from CSIRO, Australia, to Nelson, New Zealand, 1966.

Parasitoid	Approx. no. in each shipment	Date of arrival	Fate
HYMENOPTERA : BRACONIDAE			
Apanteles subandinus Blanchard			
	1,000	31 January	sent to Palmerston North 1 Feb., all dead on arrival
	1,000	5 or 12 February	12 adults emerged, liberated in Nelson

Table 22.3 Parasitoids imported from CIBC Indian Station to Nelson, New Zealand, 1966 to 1970 inclusive. Nomenclature and origin of cultures as in Sankaran & Girling (1980), and MS names as used in Rao *et al.* (1971) indicated by *.

Parasitoid	No. shipments	Approx. no. imported for each site	Release sites
I. 1966, 1966-67 season			
HYMENOPTERA : BRACONIDAE			
Agathis unicolor Schrottky	9	1,350	Lincoln
(= *A. unicolorata* (Shenefelt))	3	950	Palmerston North
	1	425	Nelson
Apanteles scutellaris Muesebeck	6	945	Lincoln
Apanteles subandinus Blanchard	9	2,685	Lincoln
	3	1,175	Nelson
	2	350	Palmerston North
Chelonus curvimaculatus Cameron	2	440	Lincoln
(= *Microchelonus curvimaculatus*)	3	825	Nelson
(Cameron)	1	750	Palmerston North
Orgilus lepidus Muesebeck	21	11,787	Lincoln
	7	2,500+?	Nelson
	6	5,850	Palmerston North
ENCYRTIDAE			
Copidosoma sp.	1	8,000	Lincoln
	2	62,000	Nelson
Copidosoma koehleri Blanchard	6	169,000	Lincoln
	1	12,000	Nelson
	1	18,500	Palmerston North
ICHNEUMONIDAE			
Campoplex haywardi Blanchard	1	55	Lincoln
Diadegma molliplum (Holmgren)			
(= *D. stellenboschense*) (Cameron)	5	510	Lincoln
Temelucha sp. *platensis* group	3	1,260	Lincoln
(Brèthes)	1	210	Nelson
	1	80	Palmerston North
II. 1968			
ENCYRTIDAE			
Copidosoma koehleri Blanchard	2	254,000	Lincoln
III. 1969-1970 season			
BRACONIDAE			
Agathis unicolor (Schrottky)	2	435	Lincoln
	3	500	Nelson

Table 22.3 continued

Parasitoid	No. shipments	Approx. no. imported for each site	Release sites
Apanteles scutellaris Muesebeck	2	530	Lincoln
	3	495	Nelson
Apanteles subandinus Blanchard	2	445	Lincoln
	5	915	Nelson
Bracon gelechiae Ashmead	2	265	Lincoln
	6	1,400	Nelson
Chelonus curvimaculatus Cameron	1	300	Lincoln
	1	400	Nelson
Orgilus lepidus Muesebeck	2	1,370	Lincoln
	3	1,150	Nelson
Orgilus parcus Turner	2	665	Lincoln
	6	2,040	Nelson
ENCYRTIDAE			
Copidosoma koehleri	1	150	Lincoln
(= *C. uruguayensis* Tachikawa)	6	1,345	Nelson
ICHNEUMONIDAE			
Campoplex haywardi Blanchard	1	125	Lincoln
	1	77	Nelson
Diadegma molliplum (Holmgren)	2	155	Lincoln
	2	170	Nelson
Diadegma turcator Aubert	1	100	Lincoln
(= *Diadegma 'raoi'* Gupta)*	2	110	Nelson
Eriborus trochanteratus (Morley)	2	465	Lincoln
(= *Diadegma 'surendrai'* Gupta)*	3	485	Nelson
Temelucha sp. *platensis* group	2	310	Lincoln
(Brèthes)	2	200	Nelson

In late March 1971, 800 adult *Apanteles subandinus* Blanchard were collected from the field in Nelson and sent to Lincoln for release; only a minor proportion were female (DSIR files).

Examination of Oamaru and Lincoln tubers and foliage for parasitised PTM was undertaken sporadically from mid 1967 until late 1973 (C.T. Jessep pers. comm.). The first recorded field recovery was of *A. subandinus* from Oamaru in June 1967. It appears to have established in that region because it was recovered each year until sampling ceased. In the Nelson area, from the last releases (1969/70), four species, *A. subandinus*, *Copidosoma koehleri*, *O. parcus* and *B. gelechiae*, were known to have bred in the field for at least one generation that season. A subsequent sweep-net survey showed only *A. subandinus* to be established on PTM. Several *O. parcus* were swept from red clover crops in 1970-71 but were suspected to have developed on armyworm or cutworm (DSIR files).

No survey for parasitised PTM in potato foliage has been carried out in the North Island. Furthermore, tubers have been examined only at Pukekohe, from where *A. subandinus* was

reared in 1970 (DSIR files). Since none were released there, it is assumed that *A. subandinus* may have been transported to Pukekohe in potatoes from Palmerston North (where 350 parasitoids were released in 1966), or from the South Island. In Canterbury, it has apparently established at least in the Lincoln area (S.L. Goldson pers. comm.).

Diadegma semiclausum Hellén, a parasitoid of diamondback moth *Plutella xylostella* (L.) (Chapter 24), also attacks PTM. In New Zealand it has been bred from this host in Oamaru, Lincoln, Nelson and Auckland (DSIR files).

Evaluation

The surveys for parasitoid establishment, carried out incidentally to other field work, did not permit an assessment of levels of PTM parasitism or possible influence on host populations except in Auckland. There, Foot (1979) concluded that *A. subandinus*, which was active in winter, probably delayed PTM reaching high densities by three to four weeks, i.e. one generation in early summer. This delay effected some control but overall the parasitoid gave little economic control of the host. This finding confirms other reports where this insect, by itself, failed to significantly reduce tuber damage (Foot 1979). In winter, however, *A. subandinus*-induced mortality of 45% suggested a role in the reduction of the overwintering population. Nevertheless, sufficient hosts survived to initiate a serious PTM problem the following summer when parasitism by *A. subandinus* was about 10-15% in the tuber population (Foot 1979). The parasitoid-host relationship on foliage was not investigated.

Conclusions

Between 1949 and 1971 in excess of 580,200 individual PTM parasitoids of 17 species, in 60 consignments from three countries, were imported into New Zealand. When this effort is matched by more surveys and subsequent evaluations, a sound decision will then be possible as to the necessity for further introductions. Studies of their biology and ecology, especially the work of Oatman as listed in Flanders & Oatman (1987), and others such as Kfir (1981), Broodryk (1969), will be of assistance in the selection of a suitable parasitoid(s). In addition, more parasitoids are described or located as PTM invades new areas where it is then commonly attacked by local parasitoids on other host(s). An example of this situation has recently been reported from the U.S.S.R. (Izhevskiy 1985, Logvinovskaya 1982).

In very few cases have parasitoids alone given control of PTM (Raman 1980), and other factors must also be considered before further importations commence. Unfortunately, New Zealand does not have many susceptible weeds which act as important reservoirs of host material between crops and between seasons (DSIR files, Haines 1977). Despite this paucity, *A. subandinus* has survived in winter on PTM inhabiting the normally plentiful volunteer potatoes and other solanaceous hosts. Furthermore, consideration must be given to the apparent necessity for a complex of complementary PTM parasitoids (Cruickshank & Ahmed 1973, Flanders & Oatman 1987, Graf 1917, Sankaran & Girling 1980, Watmough *et al.* 1973). Because of this complexity the most rewarding current method of PTM control may be the use of integrated pest management incorporating pesticides, resistant cultivars and soil management with emphasis on pheromone utilization.

Acknowledgements

This review is partly based on the records of B.B. Given (1964-67) and E.W. Valentine (1969-70), Entomology Division, DSIR, who were the project leaders in the respective periods. Debby Hutchison, Entomology Division, DSIR, Lincoln, assisted in the preparation of this review. I appreciate the unpublished information supplied by the following people: J.W. Marshall, C.T. Jessep, J.D. Fletcher and N.A. Martin of DSIR, S.L. Goldson of MAFTech, and M.A. Wood (nee Foot).

Literature Cited

Amonkar, S.V.; Pal, A.K.; Vijayalakshmi, L.; Rao, A.S. (1979) Microbial control of potato tuber moth *Phthorimaea operculella* (Zell.) *Indian journal of experimental biology* 17, 1127-1133.

Anonymous (1979) Entomology. *International Potato Center annual report CIP 1979*, 42-45.

Anonymous (1982) Entomology. *International Potato Center annual report CIP 1982*, 61-62.

Anonymous (1986) Integrated pest management. *International Potato Center annual report CIP 1985*, 73-81.

Anonymous (1987) Integrated pest management. *International Potato Center annual report CIP 1986-87*, 99-107.

Bald, J.G.; Helson, G.A.H. (1944) Estimation of damage to potato foliage by potato moth *Gnorimoschema operculella* (Zell.). *Journal of the Council for Scientific and Industrial Research, Australia* 17, 30-49.

Bedi, A.S. (1974) Potato tuber moth survey 1974. *New Zealand potato bulletin, December* 55, 4-5.

Bennett, F.D. (1984) Biological control in IPM. *Report of the XXII Planning Conference on Integrated Pest Management, Peru*, 189-197.

Berthon, H. (1855) On the potato moth. *Papers and proceedings Royal Society Van Dieman's Land* 3, 76-80.

Briese, D.T. (1982) Genetic basis for resistance to a granulosis virus in the potato moth *Phthorimaea operculella*. *Journal of invertebrate pathology* 39, 215-218.

Broodryk, S.W. (1969) The biology of *Chelonus* (= *Microchelonus*) *curvimaculatus* Cameron (Hymenoptera: Braconidae). *Journal of the Entomological Society of Southern Africa* 32, 169-189.

Chaudhary, R.; Prasad, T.; Raj, B.T. (1983) Field evaluation of some exotic parasitoids of potato tubermoth, *Phthorimaea operculella* (Zell.). *Indian journal of entomology* 45, 504-506.

Clausen, C.P. (ed.) (1978) Introduced parasites and predators of arthropod pests and weeds: a world review. *Agricultural research service, United States Department of Agriculture, agricultural handbook* 480, 545 pp.

Cock, M.J.W. (ed.) (1985) A review of biological control of pests in the Commonwealth Caribbean and Bermuda up to 1982. *Technical communication, Commonwealth Institute of Biological Control* 9, 218 pp.

Common, I.F.B. (1970) Lepidoptera. Pp. 765-866 in, The insects of Australia. Division of Entomology, Commonwealth Scientific and Industrial Research Organization, Melbourne University Press.

Cruickshank, S.; Ahmed, F. (1973) Biological control of potato tubermoth *Phthorimaea operculella* (Zell.) (Lep.:Gelechiidae) in Zambia. *Technical bulletin, Commonwealth Institute of Biological Control* 16, 147-162.

DSIR, Entomology Division, file BC 1/4.

Flanders, R.V.; Oatman, E.R. (1982) Laboratory studies on the biology of *Orgilus jenniae* (Hymenoptera: Braconidae), a parasitoid of the potato tuberworm, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). *Hilgardia* 50, 1-33.

Flanders, R.V.; Oatman, E.R. (1987) Competitive interactions among endophagous parasitoids of potato tuberworm larvae in southern California. *Hilgardia* 55, 1-34.

Foot, M.A. (1974a) Field assessment of several insecticides against the potato tuber moth (*Phthorimaea operculella* Zell. (Lepidoptera, Gelechiidae) at Pukekohe. *New Zealand journal of experimental agriculture* 2, 191-197.

Foot, M.A. (1974b) Cultural practices in relation to infestation of potato crops by the potato tuber moth. I. Effect of irrigation and ridge width. *New Zealand journal of experimental agriculture* 2, 447-450.

Foot, M.A. (1975) Potato tuber-moth, *Phthorimaea operculella* (Zeller), life-cycle. *DSIR information series* 105/15.

Foot, M.A. (1976a) Laboratory assessment of several insecticides against potato tuber moth *Phthorimaea operculella* Zeller (Lepidoptera, Gelechiidae). *New Zealand journal of agricultural research* 19, 117-125.

Foot, M.A. (1976b) Cultural practices in relation to infestation of potato crops by the potato tuber moth. II. Effect of seed depth, re-moulding, pre-harvest defoliation, and delayed harvest. *New Zealand journal of experimental agriculture* 4, 121-124.

Foot, M.A. (1976c) Susceptibility of twenty potato cultivars to the potato moth at Pukekohe: a preliminary assessment. *New Zealand journal of experimental agriculture* 4, 239-242.

Foot, M.A. (1979) Bionomics of the potato tuber moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae), at Pukekohe. *New Zealand journal of zoology* 6, 623-636.

Fouda, H.G.; Seiber, J.N.; Bacon, O.G. (1975) A potent sex attractant for the potato tuberworm moth. *Journal of economic entomology* 68, 423-427.

Georghiou, G.P. (1981) The occurrence of resistance to pesticides in arthropods. An index of cases reported through 1980. *Food and Agriculture Organisation of the United Nations, Rome* 172 pp.

Goldson, S.L.; Emberson, R.M. (1985) The potato moth *Phthorimaea operculella* (Zeller) – its habits, damage potential and management. Pp. 61-66 in Hill, G.D.; Wratt, G.S. (eds), Potato growing; a changing scene. *Special publication, Agronomy Society of New Zealand* 3.

Graf, J.E. (1917) The potato tuber moth. *United States Department of Agriculture technical bulletin* 427, 56 pp.

Greathead, D.J. (ed.) (1976) A review of biological control in western and southern Europe. *Technical communication, Commonwealth Institute of Biological Control* 7, 182 pp.

Haines, C.P. (1977) The potato tuber moth *Phthorimaea operculella* (Zeller): a bibliography of recent literature and a review of its biology and control on potatoes in the field and in store. *Report of the tropical products institute* G112, 15 pp.

Helson, G.A.H. (1942) Note on the effect of the acetylene treatment of potato tubers on potato moth, *Phthorimaea operculella* Zell. *Journal of the Council for Scientific and Industrial Research, Australia* 15, 268-269.

Helson, G.A.H. (1974) Insect pests. *Ministry of Agriculture and Fisheries, New Zealand, bulletin* 413, 1-196.

Huaman, Z. (1987) Inventory of Andean potato cultivars with resistance to some pests and diseases and other desirable traits. International Potato Center, Lima, Peru. 22 pp.

Izhevskiy, S.S. (1985) Review of the parasites of the potato tuber moth *Phthorimaea operculella* Zell. (Lepidoptera, Gelechiidae). *Entomological review* 64, 148-160.

Kfir, R. (1981) Fertility of the polyembryonic parasite *Copidosoma koehleri*, effect of humidities on life length and relative abundance as compared with that of *Apanteles subandinus* in potato tuber moth. *Annals of applied biology* 99, 225-230.

Kirk, T.W. (1894) Potato moth, potato-tuber moth, potato-grub. *New Zealand Department of Agriculture leaflets for farmers* 16, 3 pp.

Lloyd, D.C. (1972) Some South American parasites of the potato tuber moth *Phthorimaea operculella* (Zeller) and remarks on those in other continents. *Technical bulletin, Commonwealth Institute of Biological Control* 15, 35-49.

Logvinovskaya, T.V. (1982) Encyrtid *Copidosoma phthorimaeae* new species (Hymenoptera): A parasite of potato moth *Phthorimaea operculella* Lepidoptera, Gelechiidae. *Entomologiceskoe obozrenie* 61, 821-823. [in Russian].

Matthiessen, N.J.; Christian, R.L.; Grace, T.D.C.; Filshie, B.K. (1978) Large-scale field propagation and the purification of the granulosis virus of the potato moth *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae). *Bulletin of entomological research* 68, 385-391.

Meisner, J.; Ascher, K.R.S.; Lavie, D. (1974) Phagostimulants for the larva of the potato tuber moth *Gnorimoschema operculella* Zeller. *Zeitschrift für angewandte Entomologie* 77, 77-106.

Morgan, W.L. (1931) The tomato stem caterpillar *Phthorimaea plaesiosema* Turner. *Agricultural gazette of N.S.W.* December, 919-921.

Muggeridge, J. (1932) The tomato stem borer *Gnorimoschema plaesiosema* Turner. *New Zealand journal of agriculture* 45, 329-331.

Muggeridge, J. (1936) The potato-tuber moth. *New Zealand journal of agriculture* 52, 85-88.

Nabi, M.N.; Harrison, R.A. (1984) Laboratory tests on mating competition between thiotepa sterilised and normal males of the potato moth *Phthorimaea operculella* Lepidoptera Gelechiidae. *Annals of applied biology* 104, 423-426.

Oatman, E.R.; Platner, G.R. (1974) Parasitization of the potato tuberworm in southern California. *Environmental entomology* 3, 262-264.

Passlow, T.; Rossiter, P.D. (1973) Insecticides for the protection of stored potatoes. *Queensland journal of agricultural and animal sciences* 30, 151-155.

Persoons, C.J.; Voerman, S.; Verwiel, P.E.J.; Ritter, F.J.; Nooyen, W.J.; Minks, A.K. (1976) Sex pheromone of the potato tuberworm moth *Phthorimaea operculella*: isolation, identification and field evaluation. *Entomologia experimentalis et applicata* 20, 289-300.

Picard, F. (1912) La teinge des pommes de terre *Phthorimaea operculella*. Annual service des epiphyties 1. Pp 106-176 in Graf, J.E. (1917) The potato tuber moth. *United States Department of Agriculture technical bulletin* 427, 56 pp.

Povolný, D. (1973) *Scrobipalpopsis solanivora* sp. n. – a new pest of potato *Solanum tuberosum* from Central America. *Acta universitatis agriculturae* 21, 133-146.

Raman, K.V. (1980) Potato tuber moth. *Technical information bulletin, International Potato Center, Peru* 3, 14 pp.

Raman, K.V.; Booth, R.H. (1983) Evaluation of technology for integrated control of potato tuber moth in field and storage. *Technology evaluation series, International Potato Center, Peru* 10, 18 pp.

Raman, K.V.; Palacios, M. (1982) Screening potato for resistance to potato tuberworm. *Journal of economic entomology* 75, 47-49.

Ramirez, E.; Cermeli, M.; van Balen, L.; Garcia, D.; Sandoval, J.R.; Nieves, M. (1973) Chemical control of the tomato leaf miner *Phthorimaea operculella* in the States of Aragua and Lara. *Agronomia tropical* 23, 393-400.

Rao, V.P.; Ghani, M.A.; Sankaran, T.; Mathur, K.C. (1971) A review of the biological control of insects and other pests in South East Asia and the Pacific region. *Technical communication, Commonwealth Institute of Biological Control* 6, 149 pp.

Sankaran, T.; Girling, D.J. (1980) The current status of biological control of the potato tuber moth. *Biocontrol news and information* 1, 207-211.

Shelton, A.M.; Wyman, J.A. (1979a) Potato tuberworm damage to potatoes under different irrigation and cultural practices. *Journal of economic entomology* 72, 261-264.

Shelton, A.M.; Wyman J.A. (1979b) Time of tuber infestation and relationship between pheromone catches of adult moths, foliar larval populations and tuber damage by the potato tuberworm. *Journal of economic entomology* 72, 599-601.

Shelton, A.M ; Wyman, J.A.; Mayor, A.J. (1981) Effects of commonly used insecticides on the potato tuberworm and its associated parasites and predators in potatoes. *Journal of economic entomology* 74, 303-308.

Springett, B.P.; Matthiessen, J.N. (1975) Predation on potato moth, *Phthorimaea operculella* (Lepidoptera : Gelechiidae), by the western silvereye, *Zosterops gouldi* (Aves: Zosteropidae). *Australian journal of zoology* 23, 65-70.

Thal, J. (1979) Investigations on the presence of the potato tuber-moth, *Phthorimaea operculella* Zeller (Lep. Gelechiidae) in storehouses by the use of the pheromone trap. *Anzeiger für Schädlingskunde Pflanzenschutz Umweltschutz* 52, 44-47.

Thomas, P.; Srirangarajan, A.N.; Joshi, M.R.; Janave, M.T. (1980) Storage deterioration in gamma irradiated and unirradiated Indian potato *Solanum tuberosum* cultivars under refrigeration and tropical temperatures. *Potato research* 22, 261-278.

Valencia, L. (1985) IV. Course for up-dating knowledge on potato cultivation, September 18-21st: Potato seed moths. Identification, distribution and control. International Potato Center, Area 1, Bogota Colombia, 20 pp.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Watmough, R.H.; Broodryk, S.W.; Annecke, D.P. (1973) The establishment of two imported parasitoids of potato tuber moth *Phthorimaea operculella* in South Africa. *Entomophaga* 18, 237-249.

Pieris rapae (L.), small white butterfly (Lepidoptera: Pieridae)

A.M. FERGUSON

Pest Status

Pieris (= *Artogeia*) *rapae* (L.), is commonly known as the small white butterfly or, in North America, the imported cabbage worm (Kelleher & Hulme 1984). Its accidental introduction into New Zealand in 1929-1930 is documented by Muggeridge (1942). The butterfly quickly reached pest status because the local conditions were ideal for rapid dispersal and multiplication. By 1933, adults could be 'seen in millions flying everywhere in Hastings' (Muggeridge 1942) and a year later the pest had spread throughout the North Island. By 1936 it had dispersed throughout the South Island.

The life cycle of this insect in New Zealand has been described by Muggeridge (1931, 1942) and Ferguson (1984). Larvae feed voraciously causing severe foliar damage to plants (Given 1944) from four families: Brassicaceae, e.g. brussels sprouts, cabbage, radish, cauliflower, rape, swedes, turnips, kale; Tropaeolaceae, e.g. nasturtium, canary-vine; Resedaceae, e.g. mignonette and Capparidaceae, e.g. various *Cleome* species (Muggeridge 1942). Greater larval damage can be tolerated on animal forage crops than on crops grown for human consumption. Therefore, although forage crops are generally left unsprayed, vegetable crucifers grown from spring until autumn require regular applications of insecticide.

Background

Muggeridge (1931) summarised the control exerted by parasitoids and disease on *P. rapae* populations overseas. In the U.S.A., the larval parasitoid *Apanteles* (= *Cotesia*) *glomeratus* (L.) (Braconidae) and the pupal parasitoid *Pteromalus puparum* (L.) (Pteromalidae) were known to cause high host mortality. In Europe, these two parasitoids, along with *A. rubecula* (Marshall) and the tachinids *Phryxe vulgaris* (Fallén) and *Compsilura concinnata* Meigen, formed the major components of parasitoid control. The same complex, with the exception of *A. rubecula*, is also present in Canada (Kelleher & Hulme 1984).

In each of these geographical regions 'wilt' disease was an additional major component of biological control. This is now recognised as a naturally occurring granulosis virus (Kelleher & Hulme 1984) which often causes high mortality in field populations at the larval (Muggeridge 1931, DSIR files) and pupal (Kelsey 1962, Ashby & Pottinger 1974) stages of the butterfly in New Zealand. If half-grown larvae are infected, they complete their normal feeding, whereas young larvae die quickly (DSIR files). The virus can remain viable in the soil for at least three years (DSIR files).

Other diseases of *Pieris rapae* which occur in New Zealand are the fungus *Zoophthora radicans* Batko, then known as *Entomophthora sphaerosperma* Fresenius (Lowe 1956, B.B. Given pers. comm.), the microsporidian *Nosema mesnili* Paillot (Ashby & Pottinger 1974), a laboratory-only polyhedral virus, and bacteria (DSIR files). In addition, host mortality is increased by constant predation by arthropods and birds. A list of predators has been compiled for New Zealand and overseas by Ashby (1971).

In the late 1920s there was little doubt that biological factors were able to exert a considerable degree of regulation on butterfly populations overseas. This information, combined with the threatening increase in numbers of *P. rapae*, provided the incentive to commence a biological control programme in New Zealand. The initiation, in 1931, and subsequent progress is summarised by Muggeridge (1943).

Importations, Releases and Recoveries

Four parasitoids were imported in the attempt to control *P. rapae*. *A. glomeratus* cocoons, *Pteromalus puparum* inside host pupae and *A. rubecula* probably as cocoons, were obtained from the Farnham House Laboratory of the Imperial Institute of Entomology (now CIBC), England. One importation of *A. glomeratus* cocoons came from the Bureau of Entomology, Washington, U.S.A. A single shipment of *Compsilura concinnata* was obtained from Canada.

Apanteles glomeratus (L.) (Hymenoptera: Braconidae)

From 1931-34 importations of *A. glomeratus* from England totalled over 500,000 cocoons in three shipments. The extensive and well-planned programme of field releases throughout the North Island is documented by Muggeridge (1943). Field surveys in the major release area in Hawke's Bay recovered small numbers of *A. glomeratus* in that season and in the season immediately following releases, but no recoveries were recorded in subsequent years. A total of more than 250,000 adults was liberated throughout the North Island.

During the 1938-39 season 6,000 cocoons of American *A. glomeratus* were imported from the Bureau of Entomology, Washington, U.S.A. (Todd 1962). This material was secured from *P. rapae* hosts, whereas the Farnham House supplies were obtained from *P. brassicae* (L.) (DSIR files). At Nelson in the South Island, 2,317 adults were prematurely liberated late in 1938 when the parasitised host colony became severely infected with polyhedral virus. Adults were recovered immediately in the same season, up to 3 km from the original point of release, but no recoveries were made during the last months of the season (DSIR files). This absence of *A. glomeratus* in late summer was also observed by Todd (1960, 1962). By 1943-44, this parasitoid was well established in Nelson. A single release was undertaken outside the district that season, followed by other releases from 1944 until 1947 (DSIR files). This included a release in Hawke's Bay in 1944/45 (DSIR 1945). In 1960, Todd (1962) released 700 adults at Palmerston North. This release followed an intensive three year survey of crucifer crops in the southern North Island in the 1955-1958 seasons (Todd 1959) which failed to locate this species. In 1959, however, Cumber & Eyles (1961) swept six adults from six crucifer crops in the area of the previous survey by Todd. The presence of *A. glomeratus* was confirmed in 1960-61 by Todd who suggested that it had, in fact, spread naturally from Nelson to Wellington and become established in the southern North Island sometime prior to 1959 (Todd 1962). This was up to 19 years after the original release in Nelson. It was noted in the south Auckland area (A.M. Ferguson unpublished) and must have spread, or been released, there prior to 1973. Its presence in Canterbury was recorded in 1946-47 by Kelsey (1962) and it then became widely established throughout the South Island (Todd 1962).

Both *Pteromalus puparum* from England and the American *A. glomeratus* were liberated on Chatham Island in 1954-55 (Madden 1955), but there are no reports of establishment.

Apanteles rubecula Marshall (Hymenoptera: Braconidae)

Five consignments totalling 509 specimens of *A. rubecula* were imported from England in 1938-39, probably as cocoons. They were not released as a laboratory colony could not be established (DSIR files). Muggeridge (1943) considered this parasitoid to be superior to *A. glomeratus* because it was host specific, attacked early instars thus preventing serious plant damage, was better synchronised with the life-cycle of the host and was less likely to become encapsulated.

Pteromalus puparum (L.) (Hymenoptera: Pteromalidae)

10,812 adult *P. puparum*, originally from England, were liberated in 1933 by Muggeridge in the same areas of Hawke's Bay as *A. glomeratus*. By autumn, 58% of host pupae were parasitised by *P. puparum*. Further liberations were undertaken in the next season, but

these were apparently unnecessary as the initial release had established and offspring survived to spread rapidly to at least 110 km from the initial release site. By the autumn of 1934, 89% of host pupae were parasitised (Muggeridge 1943). In the subsequent season, 1934-35, releases from laboratory colonies were made into other North Island regions, notably Wellington and Manawatu, and in 1935-36 in Auckland. Liberations into South Island districts also commenced that year. Table 23.1 summarises the releases to the end of the 1937-38 season (DSIR files).

Table 23.1 Total number of adult *Pteromalus puparum* released into various New Zealand districts, from 1935-36 to 1937-38.

District	Number
NORTH ISLAND	
Auckland, Bay of Plenty	39,305
Poverty Bay	1,200
Taranaki-Manawatu	14,935
Hawke's Bay, Wairarapa	2,450
Wellington	1,340
SOUTH ISLAND	
Nelson-Marlborough	18,265
Canterbury	120,550
Otago	27,343
Southland-Westland	4,160

It was anticipated for the 1938-39 season (DSIR files) that 100,000 adults would be released throughout the country but it is unclear whether this eventuated.

By 1938, this parasitoid had been recovered from, and established in, all regions of New Zealand (Muggeridge & Given 1941, Todd 1959, B.B. Given pers. comm.). *P. puparum* is more efficient during the latter part of the season (Todd 1962) and therefore probably does not markedly reduce host population levels until subsequent generations. This has also been observed in Virginia, U.S.A. (Lasota & Kok 1986).

Compsilura concinnata Meigen (Diptera: Tachinidae)

Unknown numbers of *C. concinnata*, at an unstated life-stage, were imported in the 1940-41 season from Canada (DSIR files) where colonies had been built-up from Quebec and eastern U.S.A. *C. concinnata* for use against the tomato hornworm, *Manduca quinquemaculata* (Haworth). In Canada, the parasitoid was recovered in the field from *Pieris rapae* in 1941 (McLeod *et al.* 1962). It was never liberated in New Zealand despite the success of laboratory colonisation (DSIR files), possibly because of concern about its host range (Muggeridge 1943).

Evaluation

Of the biological control agents of *P. rapae* known to occur in New Zealand, the parasitoids *A. glomeratus* and *Pteromalus puparum*, a granulosis virus (GV) (Kelsey 1957, 1958) and predation (Ashby & Pottinger 1974), appear to have the main impact. No single agent can

consistently be rated as the most important. The dominant mortality factor(s) can change between generations (Ashby & Pottinger 1974), over a number of seasons (Kelsey 1962, Muggeridge 1943, Todd 1960, 1962,), and in response to both population density (Todd 1960) and weather conditions (Todd 1960, Kelsey 1962).

Therefore there exists a complex and fascinating interaction amongst mortality factors, especially between the parasitoids and GV (Kelsey 1962, Laing & Levin 1982). At all times, the GV can be dominant (Levin *et al.* 1983) controlling the host (Todd 1960) or the host and parasitoids (Kelsey 1962). Adult *A. glomeratus* are resistant to GV infection (Levin *et al.* 1983). However, fewer parasitoid progeny are produced from infected hosts and the adults act as vectors of this disease (Laing & Levin 1982). Similar interactions have been reported from other *Apanteles* spp. parasitoids (Hamm *et al.* 1985). The relationship between GV and *P. puparum* remains unexplored except for Kelsey's (1962) observation that GV infected pupae were generally avoided for oviposition and that if oviposition did occur, the resultant parasitoid larvae died.

The interaction between *A. glomeratus* and GV has been shown to have a deleterious effect on *A. glomeratus* (Kelsey 1962, Pimentel 1961, Oatman 1966). It is possible that the constant and devastating presence of disease (Muggeridge 1933, 1943) (probably GV), the high level of pupal parasitism by *Pteromalus puparum* (Muggeridge 1943) and its interaction with *A. glomeratus* (Moss 1933), and severe hyperparasitism by *Eupteromalus* sp. (Muggeridge 1943, Ashby & Pottinger 1974) all acted to delay the establishment of *A. glomeratus*. This would also make detection of the parasitoid difficult.

The sequence leading to the establishment of *A. glomeratus* is described by Todd (1962). The failure of the European strain to establish from 1931-34 was originally suggested by Muggeridge (1943). He proposed that the apparent failure of this parasitoid to establish was 'no doubt due to a variety of causes' and postulated the most likely one was the origin of the parasitoid from the host *Pieris brassicae*, and its failure to adapt to *P. rapae* in New Zealand. Todd (1959) failed to recover this parasitoid at all in his survey from 1955-58. Meanwhile, the American strain had established and spread in the South Island. Todd (1962) concluded that although the two strains cannot be distinguished morphologically, it appeared that the establishment of *A. glomeratus* in the North Island resulted from the spread of the American strain from the South Island.

Conclusions

This swift programme of introductions resulted in the successful establishment of *Apanteles glomeratus* and *Pteromalus puparum*. These parasitoids, in concert with GV and predation, have reduced the serious, and probably constant, *Pieris rapae* threat to the point where damage varies with seasons and districts. About every four to six years biological controls fail to prevent serious butterfly damage to forage crops (Lowe 1956, DSIR files) and it remains imperative to spray summer crops, grown for human consumption, every season. The interactions between the host and its larval and pupal parasitoids and GV would provide an interesting long-term field study.

White butterfly has developed resistance to some insecticides overseas (Georghiou 1981). It is suggested that before this problem arises in New Zealand, consideration should be given to the introduction of a parasitoid(s), e.g. *A. rubecula* which attacks the early stages of the pest before intolerable plant damage results. Moreover, increased parasitism is desirable in the first and second butterfly generations when virus levels are frequently low (Todd 1960, Ashby & Pottinger 1974). Plant cultivars tolerant or resistant to attack (Eckenrode *et al.* 1986) and the use of *Bacillus thuringiensis* sprays (A.M. Ferguson unpublished) could be useful in the development of a programme of integrated control.

Acknowledgement

The unpublished information supplied by B.B. Given, 215 Redwood Street, Blenheim, New Zealand, is gratefully acknowledged.

Literature Cited

Ashby, J.W. (1971) A study of factors regulating populations of *Pieris rapae* Linnaeus in Canterbury, New Zealand. Ph.D. thesis, Lincoln University College of Agriculture, Canterbury, New Zealand. 455 pp.

Ashby, J.W.; Pottinger, R.P. (1974) Natural regulation of *Pieris rapae* Linnaeus (Lepidoptera: Pieridae) in Canterbury, New Zealand. *New Zealand journal of agricultural research* 17, 229-239.

Cumber, R.A.; Eyles, A.C. (1961) Insects associated with the major fodder crops in the North Island. *New Zealand journal of agricultural research* 4, 390-408.

DSIR, Entomology Division, file BC 1/4.

Eckenrode, C.J.; Dickson, M.H.; Lin, J. (1986) Resistance in crucifers to diamondback moth and other lepidopterous pests. Pp. 129-135 in, Diamondback moth management *Proceedings of the 1st international workshop, Taiwan, 1985*, 129-136.

Ferguson, A.M. (1984) White butterfly, *Pieris* (= *Artogeia*) *rapae* (L.), life cycle. *DSIR information series no.* 105/10; 1st revision. 3 pp.

Georghiou, G.P. (1981) The occurrence of resistance to pesticides in arthropods. An index of cases reported through 1980. Food and agriculture organisation of the United Nations Rome. 172 pp.

Given, B.B. (1944) The relative food-consumption of diamond-back moth and white butterfly larvae. *New Zealand journal of science and technology* 26, 195-197.

Hamm, J.J.; Nordlung, D.A.; Marti, O.G. (1985) Effects of a nonoccluded virus of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on the development of a parasitoid, *Cotesia marginiventris* (Hymenoptera: Braconidae). *Environmental entomology* 14, 258-261.

Kelleher, J.S.; Hulme, M.A. (1984) Biological control programmes against insects and weeds in Canada 1969-1980. Commonwealth Agricultural Bureaux, England. 410 pp.

Kelsey, J.M. (1957) Virus sprays for control of *Pieris rapae* L. *New Zealand journal of science and technology* 38, 644-646.

Kelsey, J.M. (1958) Control of *Pieris rapae* by granulosis viruses. *New Zealand journal of agricultural research* 1, 778-782.

Kelsey, J.M. (1962) Interaction of virus and insect parasites of *Pieris rapae* L. *Proceedings of the 11th International Congress of Entomology* 2, 790-796.

Laing, J.E.; Levin, D.B. (1982) A review of the biology and a bibliography of *Apanteles glomeratus* (L.) (Hymentoptera: Braconidae). *Biocontrol News and Information* 3, 7-23.

Lasota, J.A.; Kok, L.T. (1986) Parasitism and utilization of imported cabbageworm pupae by *Pteromalus puparum* (Hymenoptera: Pteromalidae). *Environmental entomology* 15, 994-998.

Levin, D.B.; Laing, J.E.; Jaques, R.P.; Corrigan, J.E. (1983) The transmission of the granulosis virus of *Pieris rapae* by the parasitoid *Apanteles glomeratus*. *Environmental entomology* 12, 116-170.

Lowe, A.D. (1956) Control of insect pests of brassica crops in New Zealand. *New Zealand journal of agriculture* 93, 341-353.

Madden, E.A. (1955) A record of the white butterfly *Pieris rapae* L. on Chatham Island. *New Zealand entomologist* 1, 5.

McLeod, J.H.; McGugan, B.M.; Coppel, H.C. (1962) A review of the biological control attempts against insects and weeds in Canada. Parts I and II. *CIBC Technical Communication* No. 2, 216 pp.

Moss, J.E. (1933) The natural control of the cabbage caterpillars, *Pieris* spp. *Journal of animal ecology* 2, 210-231.

Muggeridge, J. (1931) *Pieris rapae*: A recently introduced cabbage pest. *New Zealand journal of agriculture* 42, 428-432.

Muggeridge, J. (1933) The white butterfly *Pieris rapae* and its parasites. *The New Zealand journal of agriculture* 47, 135-142.

Muggeridge, J. (1942) The white butterfly *Pieris rapae* L. I. Its establishment, spread, and control in New Zealand. *New Zealand journal of science and technology* 24A, 107-129.

Muggeridge, J. (1943) The white butterfly *Pieris rapae* L. II. Parasites of the butterfly III. Introduction of parasites, method, and technique. *New Zealand journal of science and technology* 25, 1-30.

Muggeridge, J.; Given, B.B. (1941) The white butterfly and the diamond backed moth. *New Zealand journal of agriculture* 63, 371-377.

Oatman, E.R. (1966) An ecological study of cabbage looper and imported cabbage-worm populations on cruciferous crops in southern California. *Journal of economic entomology* 59, 1134-1139.

Pimentel, D. (1961) Natural control of caterpillar populations on cole crops. *Journal of economic entomology* 54, 889-892.

Todd, D.H. (1959) Incidence and parasitism of insect pests of cruciferous crops in the North Island – evaluation of data, 1955-58 seasons. *New Zealand journal of agricultural research* 2, 613-622.

Todd, D.H. (1960) Virus disease effectively controls white butterfly. *New Zealand journal of agriculture* 10, 83-85.
Todd, D.H. (1962) The establishment of *Apanteles glomeratus* (Linnaeus) in the North Island, New Zealand. *New Zealand journal of science* 5, 3-7.

Plutella xylostella (L.), diamondback moth (Lepidoptera: Yponomeutidae)

W.P. THOMAS and A.M. FERGUSON

Pest Status

Plutella xylostella (L.) (= *P. maculipennis* (Curtis)) is an important pest of cruciferous crops in New Zealand. It is cosmopolitan in distribution because its extreme adaptability to varied ecological and climatic conditions has enabled it to survive from near the Arctic to the tropics. *P. xylostella* was first recorded in New Zealand around 1873 (Thomson 1922), and Meyrick (1885) reported the presence of *P. xylostella* from several New Zealand localities. Several other species within the genus *Plutella* were described from New Zealand and its offshore islands by Meyrick (1885). Dugdale (1973), on the basis of larval, pupal and genitalic characters, confirmed that three species, *P. xylostella*, *Plutella antiphona* Meyrick and *Rhigognostis sera* Meyrick (previously *Plutella sera* (Meyrick)), were present. The first two mentioned commonly occur on brassicas at Pukekohe (A.M. Ferguson unpublished) where *P. xylostella* is the dominant species. In this review, most of the information presented relates to *P. xylostella*. No research has been conducted specifically on the bionomics of *P. antiphona* or *R. sera*.

A comprehensive bibliography by Talekar *et al.* (1985) summarises research on the biology, ecology and control of *Plutella* spp. overseas. Kirk (1894), Muggeridge (1930) and Robertson (1939) described aspects of the biology and damage caused by *Plutella* '*xylostella*' in New Zealand, but there is no information available on the seriousness of the damage caused by *P. antiphona* and *R. sera* . Adult *P. xylostella* are nocturnal in habit. Neonate larvae mine the leaves of the host plant leaving the upper epidermis intact, while the later tissue-feeding instars tend to skeletonize the leaf blade. Most of the tissue between the major veins is removed thus causing severe damage. Muggeridge (1930) reported that six to seven generations developed annually in New Zealand.

New Zealand hosts of *P. xylostella* are listed in Spiller & Wise (1982). Cruciferous fodder crops, mainly chou-moellier, swedes and rape, have been grown extensively in New Zealand since early European settlement to supplement the pastoral diets of sheep during the winter months. Larval damage to these crops, especially on light soils, was severe in New Zealand compared to parts of Europe (Muggeridge 1930). In some other countries, serious infestations resulting from immigrations of moths have been noted (Harcourt 1956) but in New Zealand the species survives continuously in most regions (Muggeridge 1930). It is also a major pest of brassicas grown for human consumption.

Background

Historically, chemicals have been used to control diamondback moth in this country and the major insecticide groups are still effective (P.J. Cameron pers. comm.). However, major recurrent pesticide resistance problems have occurred in countries where chemical control measures have been intensively practised (Sun *et al.* 1986, Talekar *et al.* 1985) and this has resulted in considerable interest in methods to discourage the development of resistance (C.N. Sun pers. comm.).

Bacillus thuringiensis Berliner has provided control in various countries (Talekar *et al.* 1985), including New Zealand (A.M. Ferguson unpublished), although its commercial use here is rare. Viruses, including a granulosis virus and polyhedrosis viruses, have been tested in trials overseas (Talekar *et al.* 1985).

Marsh (1917) considered that diamondback moth populations were suppressed in parts of Europe by parasitoids among which *Diadegma semiclausum* Hellén was considered the most important. Eliot-Hardy (1938) also found that natural enemies provided a high level of control in western Europe, except when moths invaded from outbreak centres. In Canada, Harcourt (1963) showed that parasitoids and reduced fecundity were the most important factors affecting intrageneration survival. World-wide, over 90 parasitoids of diamondback moth are known (Goodwin 1979) but relatively few of these have been used and distributed for biological control of this pest. In New Zealand, Robertson (1939) examined levels of parasitism by the native parasitoids *Diadegma* sp. and *Diadromus* sp. Collections of host larvae and pupae, mainly from North Island sites, yielded insignificant parasitism levels during the period when *Plutella* spp. infestations were highest. These levels were too low to contribute to control (Robertson 1939). The presence of a hyperparasitoid on *Diadegma* sp. was also observed.

In New Zealand, the naturally occurring fungus *Zoophthora radicans* (Brefeld) A. Batko has been reported to provide high autumn mortality of larvae when weather conditions are suitable and populations high (Robertson 1939). Kelsey (1966) found a crude spray mix of this fungus prepared from macerated infested host larvae gave rapid control of field infestations. However, high mortality of *P. xylostella* caused by naturally occurring *Z. radicans* was, according to Ullyett (1947), disruptive to subsequent control by parasitoids in South Africa. Predation by syrphid larvae was reported by Miller (1918), but predation by this and other arthropods and birds in New Zealand were probably not major mortality factors (Robertson 1939, Todd 1959).

In Japan, Koshihara & Yamada (1981) have identified the female sex pheromone of *P. xylostella*. More effective male moth trapping has accompanied the use of an improved four-component sex attractant blend (Chisholm *et al.* 1983) and research on mating disruption is in progress overseas (Talekar *et al.* 1985). Host plant resistance to diamondback moth and other cruciferous pests (Chapters 23 and 11) has also been investigated (Dickson & Eckenrode 1980).

This pest annually caused serious losses to cruciferous crop production in New Zealand despite the effects of climate and the presence of native parasitoids, predators and pathogens (Muggeridge 1930). Therefore, the decision was made to introduce parasitoids.

Importations, Releases and Recoveries

The information reported here was obtained from the Annual Reports of the Cawthron Institute, the DSIR, the Farnham House Laboratory of the Imperial Bureau of Entomology, England, now CIBC, and from the unpublished reports of Muggeridge (1937) and Given (1940, 1942).

At the request of IBE, M. Kozlovsky commenced collections of parasitoids in north-western France during 1928 (IBE report 1929 DSIR files). He reared *Apanteles plutellae* Kurdjumov but no shipments resulted. In 1929, the possibility of importing *A. plutellae* and *Diadegma fenestralis* (Holmgren) into New Zealand during spring 1930, was discussed with IBE but no consignments eventuated. However, correspondence continued which culminated in the collection of *P. xylostella* pupae for parasitoid rearing and colonisation in England late in 1935. Trial consignments of *Diadegma* spp. were sent to New Zealand early in 1936 following experimental work which had determined the method to be employed (DSIR files). The utilisation of the parasitoids in New Zealand was not recorded.

Details of the subsequent importations into New Zealand appear in Table 24.1.

Diadegma fenestralis (= *Angitia fenestralis*) (Holmgren) (Hymenoptera: Ichneumonidae)

From early August 1936 until mid-January 1937, *D. fenestralis* was imported into New Zealand (Given 1940). Laboratory rearing commenced immediately at Palmerston North, while mass rearing outdoors started in September 1936. From mid-January until late February 1937, six shipments arrived which comprised cocoons of *D. fenestralis* and *Diadegma semiclausum* mixed together (Table 24.1). Releases of unstated numbers of *D. fenestralis* were made at Palmerston North in 1936-37, and from a shipment which arrived in September 1936, 3,000 adults were liberated in Hawke's Bay. This release also included unknown numbers of *D. semiclausum*. From October 1936 until early 1937, consignments of both *D. fenestralis* and *D. semiclausum* were immediately sent from Palmerston North to Hawke's Bay for mass rearing in field cages. Each species was kept separate until early January 1937, when the colonies were combined. Despite high pupal mortality caused by the hyperparasite *Trichomalopsis* sp. (= *Eupteromalus*), in excess of 6,600 *Diadegma* spp. adults were released in Hawke's Bay during the first half of 1937. Mass rearing continued there until the early 1940s (Given 1942).

When the Palmerston North colonies were transferred to Nelson in August 1937, the two species were being reared together. Laboratory and field cage rearing recommenced and 31,229 *Diadegma* spp. were released in Nelson, Waimea West and Blenheim during 1937-38. Mass breeding continued at Nelson until at least 1942. However, in the opinion of Given (1940) *D. fenestralis* had probably died out of the mixed colonies and he therefore concluded that this parasitoid was never released in the South Island.

Table 24.1 Importations into New Zealand of parasitoid species for *Plutella xylostella*

Species and source	Year	Number of consignments	Number of parasitoid cocoons	Number of emerged adults	Status	Reference
Diadegma fenestralis England	1936-37	14	14,518*	4,561+?	Not recovered	Given (1940)
Diadegma semiclausum England	1936-37	11	20,830*	8,425+?	Established	Given (1940)
Diadegma fenestralis, D. semiclausum mixed England	1937	6	39,948	4,894+?	Released	Given (1940)
Apanteles plutellae Holland	1937-38	7	13,380 (in host pupae)	776	Not released	Given (1940)
	1938-39	1	300	–	Not released	DSIR files
	1940	3	5,620	–	Not released	DSIR files
Diadromus collaris Holland	1937-38	8	11,404 (in host pupae)	140	Established	Miller (1941)
	1938-39	1	200	–	Established	DSIR files
Diadromus subtilicornis Canada	1940-41	2	33+? (adults)	–	Not released	DSIR files
	1941	3	4,090	14	Not released	Given (1942)
Diadegma semiclausum Canada	1940-41	4	609+? (some adults)	–	Not released	DSIR files
	1941	3	4,921	603	Not released	Given (1942)

* Some reared from the 25,410 host pupae sent (DSIR files).

There was doubt that *D. fenestralis* was a species distinct from *D. semiclausum* because, while the diagnostic differences were clear, under certain conditions the two species could inter-breed. The morphological characters used varied widely and a range of intermediate forms could be found in both the laboratory and field (Eliot-Hardy 1938). However, they were reported as separate species (DSIR files) possibly because the fertility and sex ratio of their offspring were not examined to determine if hybrid sterility resulted from crosses.

No recovery of *D. fenestralis* has been made in New Zealand.

Diadegma semiclausum (Hellén (Hymenoptera: Ichneumonidae) European strain

This ichneumonid has been previously known as *Diadegma eucerophaga* Horstmann and *Angitia cerophaga* (Gravenhorst). Consignments of this parasitoid arrived from 12 September 1936 until 20 January 1937 (Table 24.1), but after this importations were mixed with *D. fenestralis* (Given 1940). The rearing, liberation sites and dates are the same as for *D. fenestralis*. Attack by *Trichomalopsis* sp. was observed in both the Hawke's Bay and Nelson field cages. In January 1937, 354 adult *D. semiclausum* were dispatched from Palmerston North to Canterbury Agricultural College, Lincoln, where they were reared in a greenhouse until the end of the year. Four hundred adults were released twice at Lincoln in 1937. From the Nelson colonies 31,229 were liberated there, and 10,000 in Marlborough at the end of 1937. Releases of 500 adults were made in Canterbury in 1938-39 and again in 1939-40 (DSIR files). In spring 1940, 8,100 were liberated in Alexandra and 2,400 in Auckland.

In the season of release three adult *D. semiclausum* were recovered from Hawke's Bay, six from Lincoln and 'a few' from Nelson-Marlborough and Palmerston North. The following season, 1938-39, many adults were recovered from the three South Island regions where over 70% larval parasitism was recorded. Four adults were recovered from Hawke's Bay in April 1939.

Establishment in Nelson and Marlborough was suggested in 1939 by Miller (1939), but Given (1940) waited for the parasitoid to overwinter and he considered it to be established in 1939-40. In addition, establishment occurred in the 1939-40 season in Canterbury and North Otago. No recoveries were made in Palmerston North from 1937 until 1940-41, when *D. semiclausum* was found to have established and spread rapidly. By then, it was also well established and widely dispersed in Hawke's Bay and in the northern half of the South Island.

Liberations of Nelson-reared adults in 1941-42 were planned for central and northern areas in the North Island and, in the South Island, for South Canterbury, South Otago and Southland. Apart from South Canterbury, it was not recorded if these releases eventuated. By 1945 this parasitoid was established throughout New Zealand as shown by surveys of brassica crops about that time (DSIR files). It was more abundant than *Diadromus collaris* (Gravenhorst).

D. semiclausum Canadian strain

The consignments in 1940-41 were used for laboratory rearing but the colony soon died out. From the 1941 shipments, 300 adults of each sex emerged. Rearing was undertaken for several months to allow unspecified crossbreeding experiments and the colony was subsequently allowed to die out. None were released. This strain was easy to mass rear as the adult lived longer than that of the European strain and it appeared more hardy. These observations, however, were not confirmed experimentally (Given 1942).

Diadromus collaris (= *Thyraeella collaris*)

This parasitoid was imported from colonies in England which originated from parasitoid collections in Holland. Shipments arrived in New Zealand from late October 1937 until mid-May 1938, followed by a single importation in 1938-39 (DSIR files).

(Gravenhorst) (Hymenoptera: Ichneumonidae)

Although only 61 males and 79 females emerged, field-cage rearing at Nelson was successful with a rapid increase in numbers from September to December 1938. The initial release of 240 adults was in November 1938, in the Nelson area. Large numbers of parasitised pupae were dispatched to Hawke's Bay in January 1939 where mass field-cage rearing was again successful. The indigenous hyperparasite (*Trichomalopsis* sp.) was found to attack this parasitoid but only rarely. In Nelson and Hawke's Bay 10,000 and 18,000 adult *D. collaris* respectively were released in autumn 1939 and 8,000 at Palmerston North. In both regions the field cages became overcrowded with *Plutella* spp. larvae which induced severe autumn outbreaks of the fungal disease *Z. radicans*. Despite this hindrance, high numbers continued to be released with 2,000 at Palmerston North early in 1940. From November 1940 until March 1941, 9,400 were released in Auckland, 4,100 around Levin, 2,400 at Ashburton and 650 in Alexandra.

Colonies were maintained at Nelson until at least 1942-43. Releases in 1941-42 were intended for central and northern North Island regions and southwards from mid-Canterbury in the South Island. It is unclear if these eventuated. Rearing in Hawke's Bay ceased about 1941.

Limited numbers of *D. collaris* were recovered in Palmerston North (48 adults), Nelson (17 adults) and Hawke's Bay (217 adults) following the early 1939 releases. A survey in 1939-40 found the parasitoid well established in these regions whence it had spread at least 105 km southwards in Hawke's Bay and from Nelson to Marlborough (10 adults found) (DSIR files). It was recovered from Lincoln in the 1940-41 season. By 1943-44 *D. collaris* was well established throughout the country, demonstrating its ability to spread rapidly.

Diadromus subtilicornis (Gravenhorst) (Hymenoptera: Ichneumonidae)

Laboratory colonies were not established from either of the two importations from Canada in 1940-41. In the first shipment in late November 1940, over half the 33 adults arrived dead. From the three 1941 consignments four males and 10 females emerged but again a laboratory colony was not established (Given 1942). There were no releases.

Apanteles plutellae (= *Cotesia plutellae*) Kurdjumov (Hymenoptera: Braconidae)

Consignments of *A. plutellae* from Holland to Nelson commenced in mid-November 1937 and terminated six months later. During this time, attempts were made to establish laboratory and field-cage colonies from the 304 male and 445 female emergent adults. Unfortunately these adults were weak, mated only with difficulty, and the pupae were attacked by an indigenous *Trichomalopsis* sp. A very unequal sex ratio of 202 males to one female resulted from the first generation and only a single cocoon, which failed to emerge, from the second. The colony died out and no releases were undertaken (Given 1940).

No further details have been located for the single consignment in 1938-39 nor of the three importations in 1940.

Evaluation

The importation of *Diadegma semiclausum* and *Diadromus collaris* from Europe has resulted in their widespread establishment in New Zealand. Their impact on the two most common *Plutella* spp. is unknown as studies have not distinguished *P. xylostella* from *P. antiphona*. Despite high levels of hyperparasitism recorded by Robertson (1948) during mass propagation of *D. semiclausum*, this species and *Diadromus collaris* have since provided a high level of control of the diamondback moth complex in cruciferous fodder crops (Todd 1959). Surveys conducted by Todd (1957, 1958, 1959) on these crops in the North Island indicated high levels of parasitism although few larvae were collected. Prominent causes of mortality were *Diadegma semiclausum* and, especially at high host density, a fungal infection *Zoophthora*

radicans. However, in South Island fodder crops the pest is not so well controlled and insecticides may have to be applied (DSIR files). In high value Pukekohe vegetable brassica crops, especially cabbages, parasitoids have insufficient impact on diamondback moth populations to keep damage to an acceptable level and growers must continue to rely on regular application of insecticides.

The success of the parasitoids in fodder crops has led to the export of *D. semiclausum* and *Diadromus collaris* to several other countries (Table 24.2, Waterhouse & Norris 1987).

Table 24.2 Exports of *Plutella* spp. parasitoids from New Zealand

Importing country and species	Year	Number of consignments	Number of parasitoids	Establishment	Reference
AUSTRALIA					
*Diadegma fenestralis**	1938	–	–	–	Wilson (1960)
Diadegma semiclausum	1938-39	–	'Several thousands'	Yes	Miller (1939)
	1946-47	–	–	–	Wilson (1960)
Diadromus collaris	1947	–	–	Yes	Wilson (1960)
FIJI					
Diadromus collaris	1943	1	694 (released)	–	Lever (1944)
Diadegma semiclausum	1945	1	–	–	Lever (1946)
TONGA					
Diadromus collaris	1943	1	–	–	O'Connor 1949
INDONESIA					
Diadegma semiclausum	1950	–	–	Yes	Voss (1953)
SINGAPORE					
Diadegma semiclausum	1972-73	6	1,328	–	Chuo & Timlin (1973)
Diadromus collaris	1972-73	6	320	–	Chuo & Timlin (1973)
COOK IS.					
Diadegma semiclausum	1974-75	1	–	–	Walker & Deitz (1979)
Diadromus collaris	1974-75	1	–	Yes	Walker & Deitz (1979)
Trichogramma spp.	1974-75	1	–	–	Walker & Deitz (1979)
MALAYSIA					
Diadegma semiclausum	1977-78	6	881	Yes	DSIR files
Diadromus collaris	1977-78	6	320	Yes	DSIR files

*More likely to have been *D. semiclausum* because separate rearing of *D. fenestralis* ceased in New Zealand in January 1937.

Conclusions

This programme of parasitoid introductions has resulted in the establishment of *Diadegma semiclausum* and *Diadromus collaris*. These parasitoids, together with diseases, provide adequate control of *Plutella* spp. in North Island cruciferous fodder crops, but insecticide applications are still sometimes necessary on these crops in the South Island, and are essential on brassicas grown for human consumption.

Insecticide resistance has developed overseas where insecticides have been used in frequent year round applications for control on vegetable brassicas. Integrated control measures are being developed, including the use of selective insecticides which have low toxicity to natural enemies. These and other novel techniques are summarised in Talekar *et al.* (1985). The

modification of existing spray programmes in New Zealand is currently being investigated as a means of delaying the possible development of resistance (P.J. Cameron pers. comm.). The establishment of further parasitoids may assist this approach, particularly as some of the more successful species reported by Chua & Ooi (1986) and Waterhouse & Norris (1987) have not been released in New Zealand. Any introductions should be preceded by evaluations of the pest status and host plant preferences of all *Plutella* spp. in New Zealand, as well as a re-evaluation of the role of diseases and native parasitoids.

Literature Cited

Chisholm, M.D.; Steck, W.F.; Underhill, E.W.; Palaniswamy, P. (1983) Field trapping of diamondback moth using an improved 4-component sex attractant blend. *Journal chemical ecology* 9, 113-118.

Chua, T.H.; Ooi, P.A.C. (1986) Evaluation of three parasites in the biological control of diamondback moth in the Cameron Highlands, Malaysia. Pp. 359-371 in Talekar, N.S.; Griggs, T.D. (eds), Diamondback moth management. *Proceedings of the First International Workshop, Asian Vegetable Research and Development Center, Taiwan.*

Chuo, S.K.; Timlin, J.S. (1973) Unpublished DSIR report. 5 pp.

Dickson, M.H.; Eckenrode, C.J. (1980). Breeding for resistance in cabbage and cauliflower to cabbage looper, imported cabbage worm and diamondback moth. *Journal of the American Society of Horticultural Science* 105, 782-785.

DSIR, Entomology Division file BC 1/4.

Dugdale, J.S. (1973) The genus *Plutella* (Yponomeutidae) in New Zealand and the family position of *Circoxena* (Lepidoptera). *New Zealand journal of science* 16, 1009-1023.

Eliot-Hardy, J. (1938) *Plutella maculipennis* Curt., its natural and biological control in England. *Bulletin of entomological research* 29, 343-372.

Given, B.B. (1940) Detailed report – *Plutella maculipennis*. Unpublished, DSIR files. 58 pp.

Given, B.B. (1942) *Plutella* (diamondback moth) report, March 1941-January 1942. Unpublished, DSIR files. 3 pp.

Goodwin, S. (1979) Changes in numbers in the parasitoid complex associated with the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera), in Victoria. *Australian journal of zoology* 27, 981-989.

Harcourt, D.G. (1956) Biology of the diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae), in Eastern Ontario. 1. Distribution, economic history, synonomy, and general description. *37th report of the Quebec Society for the Protection of Plants*, 155-160.

Harcourt, D.G. (1963) Major mortality factors in the population dynamics of the diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae). *Memoirs of the Entomological Society of Canada* 32, 55-66.

Kelsey, J.M. (1966) *Entomophthora sphaerosperma* (Fres.) and *Plutella maculipennis* (Curtis) control. *New Zealand entomologist* 3, 47-49.

Kirk, T.W. (1894) Shot-hole moth, diamondback moth, cabbage moth *Plutella cruciferarum*. *Report of the New Zealand Department of Agriculture*, 90-91.

Koshihara, T.; Yamada, H. (1981) Female sex pheromone of the diamondback moth, *Plutella xylostella*. *Japan agricultural research quarterly* 15, 22-28.

Lever, R.J.A.W. (1944) Annual report for the year 1943. *Agricultural journal, Fiji* 15, 73.

Lever, R.J.A.W. (1946) Annual report of entomologist for 1945. *Agricultural journal, Fiji* 17, 42.

Marsh, H.O. (1917) Life-history of *Plutella maculipennis* (diamondback moth). *Journal of agricultural research* 10, 1-10.

Meyrick, E. (1885) Description of New Zealand Micro-Lepidoptera. *Transactions and Proceedings of the New Zealand Institute* 18, 162-183.

Miller, D. (1918) The economic bearing of hover-flies. *New Zealand journal of agriculture* 17, 129-135.

Miller, D. (1939) Diamondback moth. *DSIR annual report*, 31.

Miller, D. (1941). *Plutella maculipennis* (diamondback moth). *DSIR annual report*, 16-17.

Muggeridge, J. (1930) The diamondback moth. Its occurrence and control in New Zealand. *New Zealand journal of agriculture* 51, 253-264.

Muggeridge, J. (1937) Interim report on diamondback moth and its parasites. Unpublished, DSIR files. 18 pp.

O'Connor, B.A. (1949) Some insect pests of Tonga. *Agricultural journal, Fiji* 20, 47-57.

Robertson, P.L. (1939) Diamondback moth investigation in New Zealand. *New Zealand journal of science and technology* 20, 330-364.

Robertson, P.L. (1948) *Eupteromalus* sp. as a hyperparasite. *New Zealand journal of science and technology* 29, 257-265.

Spiller, D.M.; Wise, K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR bulletin* 231, 260 pp.

Sun, C.N.; Wu, T.K.; Chen, J.S.; Lee, W.T. (1986) Insecticide resistance in diamondback moth. Pp. 359-371 in Talekar, N.S.; Griggs, T.D. (eds), Diamondback moth management. *Proceedings of the First International Workshop, Asian Vegetable Research and Development Center, Taiwan.*

Talekar, N.S.; Yang, H.C.; Lee, S.T.; Chen, B.S.; Sun, L.Y. (1985) Annotated bibliography of diamondback moth. Tropical Vegetable Information Service, Asian Vegetable Research and Development Centre Publication, 85-229.

Thomson, G.M. (1922) The naturalisation of animals and plants in New Zealand. The University Press, Cambridge, United Kingdom, 607 pp.

Todd, D.H. (1957) Incidence and parasitism of insect pests of cruciferous crops in Hawke's Bay, Wairarapa and Manawatu, 1955-56. *New Zealand journal of science and technology* 38, 720-727.

Todd, D.H. (1958) Incidence and parasitism of insect pests of cruciferous crops in Hawke's Bay, Wairarapa, Manawatu, Rangitikei, and Taranaki, 1956-57. *New Zealand journal of agricultural research* 1, 847-858.

Todd, D.H. (1959) Incidence and parasitism of insect pests of cruciferous crops in the North Island. Evaluation of data, 1955-58 seasons. *New Zealand journal of agricultural research* 2, 613-622.

Ullyett, G.C. (1947) Mortality factors in populations of *Plutella maculipennis* Curtis and their relation to the problem of control. *Entomological memoirs of the Department of Agriculture, South Africa* 2, 77-202.

Voss, H.C.C.A.A. (1953) Introduction in Indonesia of *Angitia cerophaga* Grav., a parasite of *Plutella maculipennis* Curt. *Contributions from the General Agricultural Research Station, Bogor* 134, 32 pp.

Walker, A.K.; Dietz, L.L. (1979) A review of entomophagous insects in the Cook Islands. *New Zealand entomologist* 7, 70-82.

Waterhouse, D.F.; Norris, K.R. (1987) Biological control. Pacific prospects. Inkata Press, Melbourne. 454 pp.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Spodoptera litura (F.), tropical armyworm (Lepidoptera: Noctuidae)

R.L. HILL

Pest Status

Spodoptera litura (F.) is found in Asia, New Guinea, Australia and the Pacific Islands, where it is a major pest of cotton, rice, tomato, taro and tobacco, but also attacks legumes and other vegetable crops (Hill 1975). Sufficient moths migrate from Australia each summer to establish larval populations in autumn, especially in the north of the North Island. These populations occasionally reach sufficient density to cause significant damage to vegetables such as beans, celery, silverbeet (Chenopodiaceae), cabbage and kumara tubers (sweet potato). They can also destroy the clover in pastures (Chapman 1984). Overwintering larvae have been recorded in New Zealand (DSIR files) but it remains uncertain whether this species is resident here.

Moths lay multi-layered rafts of three to five hundred eggs on the leaves of host plants or on other flat surfaces such as walls. These egg masses are normally covered with a layer of fine hair and scales from the abdomen of the ovipositing female. Larvae hatch after three or four days and begin to feed communally at night, hence the common name of the insect. Later they disperse and feed alone (Hill 1975). Fully-grown larvae are 4-5 cm long, with bold yellow and black markings (Boardman 1977). Larvae pupate underground.

Background

S. litura was not a pest before 1970. Only three adults were recorded in New Zealand (Fox 1976) in that year, but numbers then increased until in May 1973 moths were abundant north of Auckland (Fox 1975). Larval populations continued to increase gradually until the species became a significant pest in the summers of 1974 and 1975 (Chapman 1984, DSIR files). Fox (1976) collected more than 100 specimens nightly at Helensville during May 1975. It was observed that *S. litura* larvae survived mid-winter weather conditions in Auckland in 1975 and this raised fears that a pest population had become established which was adapted to a cool climate. With the prospect of a major new pest in New Zealand, a biological control project began in 1975.

A similar project had recently been carried out in the West Indies. Five species of *Spodoptera* are pests in the Caribbean, although *S. litura* is absent. *Telenomus remus* Nixon (Hymenoptera: Scelionidae) of New Guinean origin was sent to Barbados from the Indian station of CIBC in 1971. This species was released there and became widely established. Cock (1985) reported that over 80% of the *Spodoptera* spp. eggs found on various crops in Barbados were parasitised by *T. remus*. The parasitoid has since been distributed to most Caribbean islands and is thought to contribute substantially to the reduction in populations of *Spodoptera* spp. (Cock 1985).

Importations, Releases and Recoveries

Four shipments of *Spodoptera* sp. eggs parasitised by the New Guinean strain of *T. remus* were received in New Zealand from CIBC in June and July 1975. This parasitoid readily

attacked *S. litura* egg masses and also developed on the eggs of *Agrotis ipsilon* (Hufnagel), *Chrysodeixis eriosoma* (Doubleday) and *Helicoverpa armigera* (Hübner). Large numbers of parasitoids were reared and released in 1975 and 1976 (Boardman 1977). Releases of parasitised egg masses and adult parasitoids began in August 1975 and continued until December 1976. Parasitised egg masses were pinned up in areas protected from wind or rain and it was observed that adults emerged successfully from such masses. A total of approximately 500,000 parasitoids was released at sites on the Coromandel Peninsula, in Waikato, Auckland and in Northland, particularly in Kerikeri where populations of the pest were high. In May 1976, a parasitised egg mass was observed at Paihia, some distance from the nearest release site (Entomology Division DSIR 1976). This is the only known recovery of *T. remus* since releases ceased.

Evaluation

S. litura was a major pest in 1974, but during the period in which parasitoids were being released it became less common (Entomology Division DSIR 1976) and in subsequent years larval populations have declined in abundance and economic importance. It is no longer a significant pest in either pasture or vegetable crops (DSIR files). It is very unlikely that this reduction in pest numbers is the result of parasitism by *T. remus*. It is more likely that both the build-up and decline in the pest population between 1970 and 1976 is the result of unknown factors prevailing during that period which affected either the number of moths migrating to New Zealand or the survival of their progeny.

There have been no further systematic attempts since 1977 to determine whether *T. remus* has become established in New Zealand.

Conclusions

S. litura is still encountered regularly, but is now only a minor pest of New Zealand agriculture and horticulture. Further introductions of biological control agents are not justified at present but the status of *T. remus* in New Zealand should be assessed.

Literature Cited

Boardman, L. (1977) Insectary culture of *Spodoptera litura* (Lepidoptera: Noctuidae). *New Zealand entomologist* 6, 316-318.

Chapman, R.B. (1984) Pasture pests. Pp. 119-142 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Cock, M.J.W. (1985) A review of biological control of pests in the Commonwealth Caribbean and Bermuda up to 1982. *Technical communication, Commonwealth Institute of Biological Control* 9, 218 pp.

DSIR Entomology Division, file BC 1/4.

Entomology Division DSIR (1976) Annual report, 17-18.

Fox, K.J. (1975) Migrant Lepidoptera in New Zealand 1973-74. *New Zealand entomologist* 6, 66-69.

Fox, K.J. (1976) Migrant Lepidoptera in New Zealand 1974-75. *New Zealand entomologist* 6, 198-200.

Hill, D.S. (1975) Agricultural pests of the tropics and their control. Cambridge University Press. 516 pp.

PART 3.

Fruit Crop Pests

From the early 1800s, crops such as pomefruit, berryfruit and grapes were introduced into New Zealand by early European colonists. Without the stringent quarantine procedures which are now applied, many of the associated pests also established following transferral with nursery stock or infested fruit.

Concerns expressed by the biologists of the Department of Agriculture over the quality of New Zealand's horticultural produce in the 1880s, especially in relation to codling moth (Broun 1896), initiated the adoption of quality standards, the introduction of biological control programmes and the early implementation of chemical spray regimes. Biological control of fruit pests was instigated by individuals with an active interest in this area such as R.A. Wight, an orchardist at Paeroa who also exchanged beneficial insects with A. Koebele of California, and by the Department of Agriculture through the biologist T.W. Kirk (Miller 1953). Department of Agriculture staff also played an important role in the distribution of parasitoids and predators within New Zealand, including the redistribution of *Coccinella undecimpunctata* L. to orchardists (Chapter 11).

Many of the insect pests of horticulture accidentally introduced into New Zealand were accompanied by at least some of their natural enemies. For example, parasitoids of diaspid scales and mealybugs (Chapters 31 & 39) and some predators became established in this way. The Australian coccinellid, *Rodolia cardinalis* (Mulsant) was found in New Zealand in 1887 associated with cottony cushion scale (Chapter 36) on citrus and other plants near Auckland, where it was known to have a considerable impact on its host. According to Miller (1964), it was from Napier in 1889 that A. Koebele, collecting on behalf of the Californian authorities, located his main source of this predator for release into the citrus orchards of North America. Some 6,000 individuals were collected in three days, which was more than 10 times what had been procured in Australia during 135 days. Because of declining populations of this ladybird in New Zealand, the species was reintroduced from California in 1899 and on occasions from Australia. Together with the resident populations, the combined result was that infestations of cottony cushion scale were reduced markedly to occasional local outbreaks.

A range of other parasitoids and predators have been deliberately introduced and successfully established on horticultural crops in New Zealand (Chapters 26 to 43). Early attempts at biological control of orchard pests are summarised by Dumbleton (1936). One of the successful introductions was the ladybird *Cryptolaemus montrouzieri* Mulsant which was introduced variously during 1897-1924 for the control of mealybugs (Chapter 39). This species is now established in the north of the North Island. Despite attempts to establish this species elsewhere in New Zealand, it has not become established in more southern districts.

Other introduced biological control agents which have had an impact on their targets are *Phytoseiulus persimilis* Athias-Henriot on two-spotted mite, *Tetranychus urticae* Koch (Chapter 42), *Encarsia formosa* Gahan on white fly *Trialeurodes vaporariorum* (Westwood) (Chapter 43), and *Aphelinus mali* (Haldeman) on woolly apple aphid *Eriosoma lanigerum* (Hausmann) (Chapter 34). *A. mali* is reported by Miller (1964) to have had considerable impact on its host in New Zealand and it continues to play a major part in regulating host populations on unsprayed host plants.

No diseases or nematodes have been deliberately introduced to attack horticultural pests but, in the case of the lemon tree borer *Oemona hirta* (F.) (Chapter 37), biological control measures using nematodes are currently under investigation.

In New Zealand the expanding horticultural industry has been largely export led. For many years pomefruit was the dominant export crop but since the early 1980s kiwifruit has been pre-eminent. Berryfruit and stonefruit are also important for export, while citrus is largely grown for local consumption. The production of high quality fruit for overseas markets has led to the adoption of intensive or calendar spray programmes, which has precluded many opportunities for biological control of pests. Predators and parasitoids which are susceptible to insecticides have limited usefulness in regularly sprayed host situations, but nonetheless provide some control of reservoir populations of pests such as leafrollers. It is in the area of integrated pest management that introduced natural enemies have been utilised to the greatest extent in commercial horticulture. Modified spray programmes, together with the development of chemical resistance in several species of predator mites worldwide, have led to the utilisation of these pesticide resistant species in integrated mite control programmes in several horticultural crops (Chapters 38 and 42). This has been achieved without any reduction in fruit quality. Opportunities to incorporate biological control into such effective programmes will continue to arise as other species develop tolerance or resistance to commonly used pesticides, and as more selective materials are developed. Inoculative releases will remain an option in areas or in crops which are not subject to heavy pesticide use.

Literature Cited

Broun, T. (1896) *Report of the Department of Agriculture of New Zealand*, 159-161.

Dumbleton, L.J. (1936) IV. The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Miller, D. (1953) Historical review of New Zealand entomology. *Report of the seventh Science Congress, Royal Society of New Zealand, 1951*, 80-86.

Miller, D. (1964) Historical synopsis of biological control practice in New Zealand. *New Zealand science review* 22, 4-6.

Caliroa cerasi (L.), cherryslug (Hymenoptera: Tenthredinidae)

R.L. HILL and E.W. VALENTINE

Pest Status

Caliroa cerasi (L.) is a Palaearctic species which is a minor pest of rosaceous fruit trees such as cherry, pear and plum throughout Europe. It has become established in South Africa, North and South America, Australia (Carl 1972) and New Zealand, where it was first recorded in about 1870 (Thomson 1922). Here it also attacks several ornamental shrubs and can damage hawthorn hedges (DSIR files, Penman 1984, Spiller & Wise 1982).

Cherryslug overwinters underground in cocoons as the final larval stage (or eonymph) and adults emerge in late spring. Males are extremely rare in New Zealand and females are parthenogenetic. Eggs are inserted into the mesophyll of young leaves. The larvae feed by rasping the upper epidermis and mesophyll of the leaf, destroying much of the leaf surface and producing a characteristic window effect. They are black, slimy and the head is hidden beneath the thorax of the larva giving a characteristic slug-like appearance. There are seven larval instars, the last of which is yellow rather than black, and development takes three to six weeks. Mature larvae drop or crawl to the ground and spin silken cocoons underground. A proportion then enter diapause until the following spring while the remainder pupate and emerge to produce a second generation from mid-summer to autumn. The complex factors which control diapause and voltinism in *C. cerasi* are discussed by Carl (1972) and E.W. Valentine (DSIR files).

Background

It is the second generation of the cherryslug which can cause significant damage to the leaves of fruit trees and hawthorn hedges in New Zealand. *C. cerasi* is not normally a problem in commercial orchards because pesticides applied to control other pests also kill cherryslug. However, it can cause damage to unsprayed trees, or to commercial orchards where pesticide usage is infrequent.

In New Zealand, the pentatomid bugs *Glaucias amyoti* (White) and *Cermatulus nasalis* (Westwood), and the vespid *Polistes humilis* F. prey on cherryslug but no other resident parasitoids or predators have been recorded (Valentine 1967).

In 1972-73, E.W. Valentine found that a protozoan disease infected a high proportion of the cherryslug larvae collected from fruit trees in Nelson, as well as eonymphs from cocoons which had recently been imported from Europe (DSIR files). This same disease was isolated in Europe soon after and was described as *Blastocrithidia caliroae* by Lipa *et al.* (1977). Carl (1976) recognised the symptoms described by Valentine (DSIR files) as those associated with two previously unexplained periods of *C. cerasi* larval mortality which he had observed in Europe (Carl 1972). He also showed that the protozoan was responsible for 48% mortality of 2,500 larvae collected in the Rhine Valley in 1973 and for the rapid decline in a population of cherryslug near Vienna in 1972 and 1973 (Carl 1976, Lipa *et al.* 1977). Valentine (DSIR files) considered the disease to be an important factor in the ecology of *C. cerasi* populations in Nelson as well.

The natural enemies which attack cherryslug in Europe have been well reviewed by Carl (1976). A *Trichogramma* sp. attacks the eggs but it is not thought to influence the population dynamics of its host. Six other parasitoid species attack cherryslug larvae and three of these,

Lathrolestes luteolator (Gravenhorst), *Synomelix* sp., and *Rhinotorus congruens* (Holmgren) (Hymenoptera: Ichneumonidae), appear to exert some influence on pest numbers (Carl 1972, 1976).

Lathrolestes luteolator is a solitary endoparasitoid which lays its eggs in third to seventh instar cherryslug larvae. The parasitoid remains quiescent in the host until cocoon formation is completed and then develops within the host eonymph. Carl (1976) found that this was the dominant parasitoid of cherryslug in Europe and parasitised up to 66% of larvae. It occurred in over 70% of *C. cerasi* populations even when host numbers were low. He also showed that parasitoid development was controlled by the physiological state of the host, because the proportions of both host and parasitoid which diapaused in any generation were identical. In Europe, this species invariably has two generations each year.

Synomelix sp. is a univoltine parasitoid which emerges in autumn and attacks only the second generation of cherryslug in northern Europe, although in southern Europe it may have two generations each year. It prefers to lay its eggs in older cherryslug larvae but will attack larvae of any size. It overwinters as an egg or first instar larva in the cocooned host. Unlike *L. luteolator* which begins to develop in the spring, *Synomelix* sp. halts the development of its host which remains as an eonymph until midsummer when parasitoid development resumes. Carl (1976) found *Synomelix* sp. in most cherryslug outbreaks where it parasitised up to 55% of second generation larvae, but it was rare or absent from low density populations of the pest.

Rhinotorus congruens is also a solitary endoparasitoid but it develops in both cherryslug generations. Single eggs are laid in fourth to seventh instar cherryslug larvae. Like *L. luteolator*, the phenology of this species is closely synchronised with that of its host. *R. congruens* parasitises approximately 16% of larvae in outbreak populations of cherryslug, but is equally abundant in low populations of its host. This suggests that the parasitoid has a high searching capacity and may be important in suppressing *C. cerasi* populations (Carl 1976).

No other parasitoid species are thought to be important in the population dynamics of cherryslug (Carl 1976). Cameron *et al.* (1987) recorded that *Eridolius rufonotatus* (Holmgren) (Hymenoptera: Ichneumonidae) was imported into New Zealand. Although parasitised cocoons were sent, no *E. rufonotatus* emerged.

Importations, Releases and Recoveries

Importations 1923-1924

On 9 February 1923, 850 cocoons of *C. cerasi* were received from G.A.K. Marshall of the Imperial Institute of Entomology, England, and were placed in cold storage. In September, a further shipment of 400 cocoons was received from A.D. Imms at Rothamsted Experimental Station. All cocoons were presumably collected in southern England but this is not recorded. Twenty-six female and only two male *L. luteolator* emerged from mid-January to the end of April 1924 (DSIR files). Attempts were made to parasitise cherryslug larvae in the laboratory, but eventually all remaining parasitoids were released directly into the field on emergence. It is not certain how many were released. Having completed diapause, a further 29 female and six male *L. luteolator* emerged in November and December 1924. Twenty-one were released locally after parasitising some cherryslug larvae in the laboratory. In the following spring, these laboratory parasitised cherryslug yielded 21 males but no females. In subsequent field observations *L. luteolator* was not recorded (E.S. Gourlay DSIR files).

Importations 1929-1930

Approximately 50,000 larvae of *C. cerasi* were collected from Caen, northern France in July 1928. A further 1,800 larvae were collected in Essex, England. These were reared at the

Farnham House Laboratory of the Imperial Bureau of Entomology and after considerable difficulty, 6,524 cocoons were sent to New Zealand (Thompson 1930). Some of these were stored in cool conditions while the remainder were reared. By 22 February 1930, this shipment had yielded three female and three male *L. luteolator* (E.S. Gourlay DSIR files). The females were released but at least two of these were not mated. There is no record of the fate of the stored cocoons beyond this date. Dumbleton (1936) records that *Rhinotorus congruens* was released in 1929 (as *Mesoleius caninae* Bridgeman) but there is no other record of this.

Importations 1972-1974

Between February 1972 and October 1974, four shipments containing 15,620 *C. cerasi* cocoons were received from K.P. Carl of CIBC in Switzerland. These were collected in Austria, France and Germany (Table 26.1). The first shipment was received in February 1972 and contained second generation *C. cerasi*, 12% of which were parasitised by *Synomelix* sp. These emerged in October, long before hosts were available in the field for parasitism, and could not be used.

Table 26.1 Parasitoids of *C. cerasi* imported into New Zealand

Date received	Origin	Cocoons received	Parasitoids received
1923	?southern England	850	*Lathrolestes luteolator*
1923	?southern England	400	*L. luteolator*
1929	northern France Essex, England	6,524	*L. luteolator*
3 Feb 1972	Vienna, Austria	2,500	*Synomelix* sp.
20 Nov 1972	Vienna, Austria Alsace, France Bonn, W. Germany	2,070	*L. luteolator* *Rhinotorus congruens* *Synomelix* sp.
20 Oct 1973	Alsace, France Bonn, W. Germany	4,750	*L. luteolator* *R. congruens* *Vibrissina turrita*
26 Oct 1974	Alsace, France	6,300	*L. luteolator* *R. congruens*

The second shipment, which arrived in November 1972, contained first and second generation cocoons, 40% of which were parasitised. Sufficient parasitoids emerged to begin a laboratory culture using field-collected host larvae, but this eventually failed because many of these died. The cause of this mortality was a protozoan, *B. caliroae*, the discovery of which was discussed earlier. Some cocoons were stored and then incubated in the following spring. *Synomelix* sp. emerged and parasitised many larvae in the laboratory. Unfortunately, the parasitoid developed only in diapausing hosts and these made up only a small proportion of the hosts presented for parasitisation (E.W. Valentine DSIR files).

A shipment of second generation, field-collected cocoons arrived on 20 October 1973 (Table 26.1). A small sample was reared and yielded one specimen of *Vibrissina turrita* (Meigen) (Diptera: Tachinidae), but most of the cocoons were stored and then incubated

Table 26.2 Parasitoids of *C. cerasi* released in New Zealand

Year	Site	Species released	Number released
1923/24	Nelson	*L. luteolator* parasitised larvae	21 unknown
1929	Nelson	*L. luteolator* *L. luteolator*	6? unknown
1974	'Alberton', Auckland Avondale, Auckland	*R. congruens* *Synomelix* sp.	small numbers small numbers
1975	'Alberton', Auckland Kopu, Thames	*L. luteolator* *L. luteolator*	47 females, 21 males 10 females, 7 males

in spring 1974. The parasitoids which emerged were *L. luteolator* (16 males, 14 females), *Synomelix* sp. (4 males, 10 females) and *R. congruens* (7 males, 3 females). Valentine (DSIR files) reported that a small number of the *Synomelix* sp. and *R. congruens* were released at two sites in Auckland (Table 26.2) but the exact number is unknown.

Incubation continued for a further year to monitor emergence. *C. cerasi* continued to emerge in the following spring, demonstrating for the first time that this species can have a two year life cycle. One *R. congruens* also followed the development of its host and emerged in the second year.

The fourth shipment of cocoons was received on 26 October 1974 and was kept in cold-storage until spring 1975. Between 5 November and 6 December 1975, 68 *L. luteolator* were released in Auckland and Thames (DSIR files, Table 26.2). No other species were released.

Evaluation

No attempt has been made to check for the establishment of *Synomelix* sp. or *Rhinotorus congruens* since releases were made in Auckland and Thames in 1975 and 1976.

L. luteolator was first recorded in Nelson in 1963, 33 years after it was last released there. It was commonly seen at one Nelson site in 1970, and in 1972 over 50% parasitism of cherryslug larvae was recorded at Blenheim, 100 km distant from the original release site (DSIR files). It was not recorded in Auckland prior to releases made in 1974. Apart from these records, nothing is known about the distribution of *L. luteolator* in New Zealand.

Carl (1976) found that in central Europe, *L. luteolator* was a bivoltine species which sometimes attacked a high proportion of the larvae in both generations of *C. cerasi*. In Nelson, however, Valentine showed that this parasitoid attacked only the spring generation of cherryslug (DSIR files) and so is of less value as a control agent. The reason for this phenological difference is not known. Carl's (1972, 1976) studies were carried out in central Europe where maximum summer daylength is one hour longer than it is in Nelson. This may affect the voltinism of the parasitoid, although he also found that *L. luteolator* was still bivoltine at a latitude of 43.5°S, only 2.5° higher than Nelson (DSIR files). It is also possible that the strain of parasitoid from southern England or northern France established in Nelson in the 1920s may be intrinsically univoltine.

Although *L. luteolator* is less effective in New Zealand than it is in Europe, Valentine (DSIR files) found that 90% of cherryslug larvae collected in a December 1973 sample were parasitised. *L. luteolator* may therefore be an effective early season parasitoid. By February this level had reduced to 5% as the parasitoid population declined.

Epizootics of the protozoan disease *B. caliroae* can cause rapid decline in outbreak populations of *C. cerasi* both in Europe (Carl 1976) and in Nelson (DSIR files). This disease has

also added greatly to the difficulty of collecting, rearing and establishing new parasitoids of the pest in New Zealand. It may have been the cause of rearing difficulties described by Thomson (1930), just as it was in later biological control attempts (Carl 1972, 1976). Nothing is known about the distribution of this protozoan in New Zealand or about its role in the population dynamics of *C. cerasi*.

Conclusions

C. cerasi remains a minor pest on certain stonefruit trees which are not treated with insecticides. Attempts to control the pest biologically have resulted in the establishment of a strain of *L. luteolator* which has only been recorded in the north of the South Island, where it appears to be ineffective because it only attacks the less damaging of the two pest generations.

A protozoan disease, presumably introduced accidentally either with its host or on parasitoids liberated in the 1920s, has become established in Nelson and can cause high mortality of *C. cerasi* larvae.

Nothing is known about the distribution of either natural enemy, or about their role in the population dynamics of the pest. Neither has been recorded in Auckland (DSIR files).

Synomelix sp. and *Rhinotorus congruens* have been released at two sites but it is very unlikely that enough were released to establish a viable population. It appears that *L. luteolator* was established in Nelson after the release of less than 30 adults and an unknown number of parasitised larvae. It is therefore possible that this species could be established from the relatively small numbers released in Auckland and Thames in 1975. No attempt has been made to evaluate these releases.

Improved control of of *C. cerasi* in New Zealand might be achieved if the following recommendations were adopted:

1. Determine the distribution of *L. luteolator* in New Zealand
2. Determine the distribution of *B. caliroae* in New Zealand
3. Assess the roles of *L. luteolator* and *B. caliroae* in the population dynamics of *C. cerasi* in districts where they are known to occur in New Zealand
4. Survey for the establishment of parasitoids released in Auckland and Thames in 1974 and 1975
5. Introduce *B. caliroae* to areas of New Zealand where it does not occur
6. Introduce the resident strain of *L. luteolator* to areas where it does not occur
7. Introduce bivoltine *L. luteolator* and /or autumn-active parasitoids such as *Synomelix* sp. or *Rhinotorus congruens* from Europe to increase larval mortality in the second pest generation.

Acknowledgements

E.W. Valentine directed this programme from 1970 to 1978. R.L. Hill made releases in 1975. Our thanks to K.P. Carl who commented on the manuscript.

Literature Cited

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for the control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242, 51 pp.

Carl, K.P. (1972) On the biology and population dynamics of *Caliroa cerasi* (L.) (Hym., Tenthredinidae). *Zeitschrift für angewandte Entomologie* 71, 58-83.

Carl, K.P. (1976) The natural enemies of the pear-slug, *Caliroa cerasi* (L.) (Hym., Tenthredinidae), in Europe. *Zeitschrift für angewandte Entomologie* 80, 138-161.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Lipa, J.J.; Carl, K.P.; Valentine, E.W. (1977) *Blastocrithidia caliroae* sp. n., a flagellate parasite of *Caliroa cerasi* (L.) (Hymenoptera: Tenthredinidae) and notes on its epizootics in host field populations. *Acta protozoologica* 16, 121-129.

Penman, D.R. (1984) Deciduous tree fruit pests. Pp. 33-50 in Scott, R.R. (ed.) New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Spiller, P.M.; Wise K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host-plants. *DSIR bulletin* 131, 260 pp.

Thomson, G.M. (1922) Naturalisation of animals and plants in New Zealand. Cambridge University Press, Cambridge, U.K. 607 pp.

Thompson, W.R. (1930) The biological control of insect and plant pests. A report of the organisation and progress of the work of the Farnham House Laboratory. HMSO, London. 116 pp.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Coccus hesperidum L., brown soft scale (Homoptera: Coccidae)

M.G. HILL

Pest Status

Coccus hesperidum L. feeds on a wide variety of plants, and is a minor pest of citrus and ornamental trees in the north of the North Island. It can also be a problem on a wide variety of greenhouse crops and house plants (Penman 1984).

Background

Six parasitoid species and one predator have been recorded from brown soft scale (Table 27.1). There is no quantitative information on rates of parasitism of brown soft scale, and the only information on parasitoid effectiveness suggests that the scale populations are being at least partly limited by *Microterys flavus* (Howard) (Hymenoptera: Encyrtidae)(Dumbleton 1936, Gourlay 1930a). *Rhyzobius ventralis* (Erichson)(Coleoptera: Coccinellidae), which feeds on brown soft scale, was imported as a predator of *Eriococcus coriaceus* Maskell (see Chapter 45).

Importations, Releases and Recoveries

Microterys flavus (Howard) (Hymenoptera: Encyrtidae)

Microterys flavus was introduced in 1921, probably from Australia (Dumbleton 1936, Valentine & Walker 1989, Wilson 1963). There is some confusion as to whether this parasitoid was already present in New Zealand prior to this importation. Valentine & Walker (1989) state that it was present prior to 1921. Gourlay (1930b) did not record it as having been introduced in his list of entomophagous insects of New Zealand, while in another publication (Gourlay 1930a) he mentioned that the parasitoid was having a significant controlling effect upon soft scale populations but again did not mention the importation.

Dumbleton (1936) mentions its introduction in 1921, and implies that effective control was achieved following this. He does not mention its presence in New Zealand prior to 1921.

Table 27.1 Recorded natural enemies of brown soft scale (after Valentine & Walker (1989))

PARASITOIDS	PREDATORS
HYMENOPTERA: APHELINIDAE	COLEOPTERA: COCCINELLIDAE
Coccophagus scutellaris (Dalman)	*Rhyzobius ventralis* (Erichson)
Encarsia citrina (Craw)	
Euxanthellus philippiae Silvestri	
ENCYRTIDAE	
Eusemion cornigerum (Walker)	
Metaphycus claviger (Timberlake)	
Microterys flavus (Howard)	

Evaluation

It could be construed from Dumbleton's (1936) remarks that, even if the parasitoid were present prior to 1921, the introduction from Australia was of a different strain which exercised considerably more control than its native conspecific. However, Gourlay's (1930a, 1930b) failure to mention the 1921 importation, while writing of the importance of *M. flavus* suggests that he may have considered the importation as not having significantly affected *M. flavus* parasitism of brown soft scale. It is not possible to resolve this issue after the passage of some 60 years.

There is no information on the effectiveness of *Rhyzobius ventralis* as a predator of brown soft scale in New Zealand, although Wilson (1960) mentions that the beetle is 'a predator of some importance' in Western Australia.

Conclusions

Whatever the role of imported strains of *M. flavus* in controlling brown soft scale, it appears to be only a minor pest in most situations. Existing control measures are adequate and this pest is not an immediate candidate for further biological control attempts.

Literature Cited

Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Gourlay, E.S. (1930a) Some parasitic Hymenoptera of economic importance in New Zealand. *New Zealand journal of science and technology* 11, 339-343.

Gourlay, E.S. (1930b) Preliminary host-list of the entomophagous insects in New Zealand. *DSIR bulletin* 22, 1-13.

Penman, D.R. (1984) Subtropical fruit pests. Pp. 51-64 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Valentine, E.W.; Walker, A.K. (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, in press.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Wilson, F. (1963) Australia as a source of beneficial insects for biological control. *Technical communication, Commonwealth Institute of Biological Control* 3, 28 pp.

Cydia molesta (Busck), oriental fruit moth (Lepidoptera: Tortricidae)

D. RUSSELL

Pest Status

The oriental fruit moth, *Cydia* (= *Grapholita* or *Grapholitha*) *molesta* (Busck) (OFM), was accidentally introduced into New Zealand, where it was first recorded from the Auckland suburb of Mangere in March 1976 (Cox & Dale 1977) and the species was well established in the Auckland area by the end of that year. Baker (1982a, 1982b) charts the subsequent spread of the species and Russell (1987a) shows its present range – basically north of 43°S but absent from the Taranaki area and high country. The area of infestation includes the major summerfruit growing regions of Auckland and Hawke's Bay. There is no reason to think that its spread to the rest of New Zealand is anything but a matter of time.

Basically a pest of deciduous rosaceous tree fruits, OFM has been recorded in New Zealand from peach, nectarine, almond, cherry, flowering cherry, plum, pear, apple and quince. There are also a few records of OFM larvae feeding on feijoa, *Feijoa sellowiana* O. Berg (Myrtaceae), but it is doubtful if any natural oviposition occurs on this species. Quince is a preferred host (Summers 1966) but is not intensively cultivated in New Zealand. Feeding in apple fruit is certainly common in the Auckland region, especially late in the season (Baker 1982b). However, shoot and fruit feeding in stone fruit, especially peaches, is the main area of commercial concern.

In New Zealand, OFM infestations in commercially managed orchards have generally remained low, probably because of insecticide programmes directed against the lightbrown apple moth (*Epiphyas postvittana* (Walker) (Tortricidae)), a number of native leafroller species and, in apple orchards, the codling moth (*Cydia pomonella* (L.) (Tortricidae)). In an unsprayed block of peach (cv. 'Golden Queen') OFM fruit damage at harvest varied from 5 to 17% over the 1982-4 seasons compared with 1-2% in an insecticide-sprayed control block (Russell 1986). Summerfruit grown in home gardens has suffered badly, especially as infestations of brown rot (*Sclerotinia fructicola* (Winter) Rehm) are aggravated by OFM larval damage and the subsequent movement of nitidulid beetle vectors (Kable 1969). Around 30% of all rotten fruit examined in 1982-4 (Russell 1986) was associated with OFM larval damage. This was true whether total rot damage levels were low (less than 3% in an insecticide and fungicide sprayed block) or high (greater than 14% in a comparable block treated with fungicide only). There is also concern over the movement of overwintering larvae on nursery stock to areas which are not yet infested by OFM.

OFM has four generations per year in the Auckland region, and three and a small partial fourth in Hawke's Bay. Moth numbers, as monitored by pheromone traps, seem to have fallen from an initial high in the late 1970s following its arrival in New Zealand.

Background

Luck (1981) has evaluated all the known introductions of biological control agents against OFM worldwide. However, he was unable to report economic control by any species in any area even though prodigious efforts have been made, especially with the larval parasitoid *Macrocentrus ancylivorus* Rohwer (Braconidae). These attempts and the currently known parasitoid fauna of OFM in New Zealand, have been reviewed by Russell (1987b).

Parasitoids

There are a number of *Trichogramma* and *T.* (*Trichogrammanza*) spp. which are known to parasitise OFM in Australia (Bailey 1979 and pers. comm., Carver 1978 and pers. comm., Danthanarayana 1980, McLaren & Rye 1981). Some of these may be present in New Zealand (Valentine 1967 and pers. comm., Valentine & Walker 1989) but as yet no egg parasitism has been recorded. OFM larvae feed within the tissue of the shoots and fruits of the host. Larval parasitism is most readily accomplished when the larva is moving between feeding sites and when searching for a pupation site. Larval parasitism has been recorded in New Zealand only for *Meteorus cinctellus* (Spinola) (Braconidae), on one occasion. A single specimen of a *Rogas* sp. has been reared from an OFM pupa in Auckland and a *Trichomalopsis* sp. has been recorded from prepupal OFM in Havelock North (Hawke's Bay). The only other non-introduced parasitoids recorded are *Gelis cinctus* (L.) and *Gelis tenellus* (Say) (Ichneumonidae) (= *Hemiteles* sp. 1 of Thomas (1965)). *G. tenellus* has been recorded as a primary parasitoid of OFM only from Kumeu (Auckland) and *G. cinctus* from several other sites in the Auckland region. Levels of parasitism by these species taken together have not exceeded 3% over the three seasons 1981-4 at the only site so far thoroughly examined, DSIR Research Orchard, Kumeu. The *Gelis* spp. are however, important hyperparasitoids of *Glabridorsum stokesii* (Cameron), as described below.

Predators

The role of predators in limiting OFM numbers has been little studied despite considerable circumstantial evidence of the importance of generalist predators, such as *Stethorus* sp., *Harmonia* sp. (Coccinellidae), and chrysopid and hemerobiid lacewings, in the decline in importance of OFM in insecticide-free orchards in Australia (Russell 1984). The following predators were either caught in the act of consuming larvae marked with radioactive ^{58}Co or were later recovered with radioactivity in their guts at Kumeu Research Orchard (Russell 1986): the slug *Deroceras reticulatum* (Müller), the common carabid beetle *Pristonychus* (= *Laemostenus*) *complanatus* (Dejean), the salticid spider *Trite minax* (Powell) (= *T. planiceps* Simon) and the common theriid *Achaearanea veruculata* (Urquhart), which is a tangle web spider identified by MacLellan (1973) as the most important spider predator of *Epiphyas postvittana* in work in the Australian Capital Territory. There was also evidence of predation by the silvereye (*Zosterops lateralis* (Latham)) in the winter of 1982. Wearing (1975) shows this bird to be an important predator on cocooned codling moth larvae in Nelson.

Importations, Releases and Recoveries

No releases have been made in New Zealand specifically against OFM. A number of species introduced for the control of other tortricids (Chapters 29, 33) have been recorded as parasitoids of OFM.

Trigonospila brevifacies (Hardy) (Diptera: Tachinidae)

This polyphagous species was introduced to New Zealand from Australia by DSIR as a leafroller (especially *Epiphyas postvittana*) parasitoid, with releases made in the period 1967-72 (Chapter 33, Thomas 1975). The species rapidly became established and it was further distributed to Havelock North, Christchurch and Nelson in 1981-82 (J.R. Clearwater pers. comm.). O.R. Green (1984a) records the current host range in New Zealand. The fly cements its egg to the dorsal surface of the thorax of the host larva and the hatching larva enters the host directly. Emergence is from the host prepupa or pupa. Although wide spread and numerous on other hosts in the Auckland area, only two records exist for OFM – both at Kumeu Research Orchard, Auckland; in 1982 and 1984. This, plus a lack of records of

the species from OFM in Australia, probably indicates that OFM is not an ideal host, perhaps because OFM larvae are available for oviposition by this species only for short periods while changing feeding sites or seeking suitable pupation sites.

Liotryphon caudatus (Ratzeburg) (Hymenoptera: Ichneumonidae)

L. caudatus was introduced into New Zealand in 1906 (under the name *Ephialtes messor* Gravenhorst), to assist in codling moth control (Chapter 29, Dumbleton 1936) but appears to have become established only in the northern North Island. It is a solitary, external parasitoid of a number of species of Lepidoptera with overwintering cocooned larvae (Clausen 1978) and possibly of bark inhabiting Coleoptera. Recent New Zealand host records include *Stathmopoda* spp. (Lepidoptera: Stathmopodidae) (Russell unpublished). The only records from OFM in New Zealand are of wasps reared from OFM larvae and prepupae exposed in cardboard bands tied to peach tree trunks in March 1984 at Kumeu (three specimens) and at Beachaven, Auckland (one specimen) (Russell 1987b). This species does not appear to have been recorded from OFM elsewhere in the world although various other species of *Ephialtes* have been noted (Thompson 1946).

Glabridorsum (= *Gambrus*) (= *Ischnus*) *stokesii* (Cameron) (Hymenoptera: Ichneumonidae)

G. stokesii is a native of Australia where it has been known as a parasitoid of OFM since the 1930s (Allen 1932). Unsuccessful attempts have been made to introduce the species into the U.S.A. (Allen 1962). It was introduced into New Zealand in 1967 and 1969 and released over the following five years (Chapter 33, Thomas 1975) against *E. postvittana*, itself originally an Australian species. It is now established from Nelson northwards (Russell 1987a) and further attempts have been made to establish the species in Canterbury (Chapter 33, W.P. Thomas pers. comm.). In addition to OFM, *G. stokesii* is recorded in the Bay of Plenty from *Ctenopseustis obliquana* (Walker) (D. Steven pers. comm.) and from *E. postvittana*, *Ctenopseustis obliquana sensu latu* and *Planotortrix excessana sensu latu* (Tortricidae) in Nelson (W.P. Thomas pers. comm.). *G. stokesii* is recorded elsewhere as a parasitoid of *Cydia pomonella* (Helson 1939, Miller 1938) and was observed attacking this host immediately after it was released in Nelson (W.P. Thomas pers. comm.). However, it has not been encountered on this host naturally in New Zealand.

The biology of *G. stokesii* as a parasitoid of OFM in New Zealand is discussed by Russell (1987a). Townes (1969) provides a full description and illustration of the species, O.R. Green (1984b) has published an illustrated note as an aid to identification in New Zealand and Gauld (1984) gives host records from Australia.

G. stokesii was first recorded from OFM in New Zealand in February 1982, in Auckland, and was subsequently found in the seven Auckland areas surveyed in 1983-84. It has not yet been recovered from OFM in Hawke's Bay. Adult *G. stokesii* are present in the field in low numbers in the winter months and development is probably continuous throughout the winter, at least in the north.

The percentage parasitism of OFM at Kumeu Research Orchard, Auckland, as measured to take account of the greater length of time available for sampling of the parasitised pupae (Russell 1987b), varied from 21-73% per generation over the 1982-4 seasons, with higher levels later in the season. Individual weekly percentage parasitism reached 100% in February 1984 (Russell 1986, 1987a). Mortality while developing on OFM in the field is low (less than 1%). The species seems to be spreading rapidly and increasing in numbers (Russell 1986). Field records of pupal parasitism of OFM extend from November to April. *G. stokesii* is most common as a parasitoid of OFM in the second summer generation of the host (January/February). Hyperparasitism by *Gelis cinctus* and *G. tenellus* in the summer months varied around 7% in 1982-83 and 15% in 1983-4 at Kumeu (Russell 1987b). Laboratory rearing techniques for *Glabridorsum stokesii* are available (Russell 1987a, W.P. Thomas unpublished).

Evaluation

Among the natural enemies of OFM in New Zealand, only *G. stokesii* currently shows any promise of a major impact on numbers. Levels of parasitism can be high late in the season but host/parasitoid synchrony is limited by their overwintering habits. OFM overwinters as non-susceptible final instar larvae. *G. stokesii* appears to overwinter as adults or on alternative tortricid hosts, which continue their development throughout the winter, and so temporal synchrony with OFM pupating in the spring is minimal. It was not possible to demonstrate any consistent inverse density dependent relationship over 10 generations in the field (Russell 1986). However, the widespread polyphagous alternative leafroller hosts may be expected to act as a reservoir from which *G. stokesii* may rapidly reinvade orchards.

C.J. Green (1984) has shown that there is a build up in leafroller numbers through the season in an unsprayed apple orchard near Auckland. Whether the seasonal increase of parasitism of OFM by *G. stokesii* would occur in the absence of such alternative hosts remains uncertain.

The results of exposing OFM pupae to parasitism in the field under different pesticide regimes (Russell 1987b) show that *G. stokesii* is susceptible to organophosphate and carbamate insecticides, making its use in conjunction with chemical control difficult. If the initial promise of OFM control by sexual confusion using artificial pheromones is realised, then *G. stokesii* may be able to play a more prominent role.

Conclusions

Experience to date does not suggest any suitable natural enemy as a candidate for immediate introduction to New Zealand. This is particularly true while regular insecticide applications continue to be required for the control of leafrollers on pip and summerfruit. Significant contributions to integrated control strategies for OFM have been demonstrated only for parasitoid species within, or close to, their native geographical ranges or which are repeatedly inundatively released. The shift in emphasis by OFM larvae from shoot to fruit feeding as the season progresses (Russell 1986) means that any proposed attempt at biological control utilising larval parasitoids would have to consider carefully the seasonal timing of the impact of the species and the relative numbers of shoot, as opposed to fruit, infesting larvae available during such periods. However, the impact of *G. stokesii* on OFM in Auckland is of great interest and may make introduction of such species as *Macrocentrus ancylivorus* and *Glypta rufiscutellaris* Cresson (Ichneumonidae), which also overwinter on alternative tortricid hosts, attractive. *M. ancylivorus* has the ability to avoid the worst effects of organophosphate insecticides (Dunstan & Boyce 1968).

Surveys of parasitism have been carried out only in Auckland and (in a limited way) Hawke's Bay. Before any introductions are contemplated, the area surveyed should be widened, especially to search for egg parasitism by *Trichogramma*/*Trichogrammanza* species and for egg/larval parasitism by *Ascogaster quadridentata* Wesmael (Braconidae) which is a parasitoid of codling moth in New Zealand (Chapter 29), and is a significant OFM parasitoid elsewhere in the world (Allen 1932, Shaw 1983).

Literature Cited

Allen, H.W. (1932) Present status of oriental fruit moth investigations. *Journal of economic entomology* 25, 360-367.

Allen, H.W. (1962) Parasites of the oriental fruit moth in the eastern United States. *Technical bulletin, United States Department of Agriculture* 1265.

Bailey, P. (1979) An attempt to control oriental fruit moth, *Cydia molesta* Busck by mass releases of *Macrocentrus ancylivorus* Rohwer (Hymenoptera: Braconidae). *Journal of the Australian Entomological Society* 18, 211-212.

Baker, R.T. (1982a) The oriental fruit moth in pip and stone fruit. *Aglink* HPP128, (2nd revision). New Zealand Ministry of Agriculture and Fisheries. 2pp.

Baker, R.T. (1982b) The oriental fruit moth in New Zealand. *Proceedings of the 35th New Zealand Weed and Pest Control Conference*, 17-21.

Carver, M. (1978) A new subgenus and species of *Trichogramma* Westwood (Hymenoptera: Chalcidoidea) from Australia. *Journal of the Australian Entomological Society* 17, 109-112.

Clausen, C.P. (ed.) (1978) Introduced parasites and predators of arthropod pests and weeds. A world review. *United States Department of Agriculture, Agricultural Research Service; Agriculture Handbook* 480. 545 pp.

Cox, J.M.; Dale, P.S. (1977) New records of plant pests in New Zealand. 2. *New Zealand journal of agricultural research* 20, 109-111.

Danthanarayana, W. (1980) The occurrence of *Trichogramma funiculatum* an egg parasitoid of the light brown apple moth, *Epiphyas postvittana*. *Entomologia experimentalis et applicata* 28, 287-294.

Dunstan, G.G.; Boyce, H.R. (1968) Parasitism of the Oriental fruit moth *Grapholitha molesta* (Busck) (Lepidoptera: Tortricidae) in Ontario 1956-1965. *Proceedings of the Entomological Society of Ontario* (1966) 96, 100-102.

Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 898-902.

Gauld, I. (1984) An introduction to the Ichneumonidae of Australia. *British Museum of Natural History publication* 895, 405 pp.

Green, C.J. (1984) Bionomics of *Epiphyas postvittana*, *Ctenopseustis obliquana*, *Planotortrix excessana* (Lepidoptera: Tortricidae) and *Stathmopoda 'skelloni'* (Lepidoptera: Stathmopodidae) on apple cv. 'Dougherty' in Auckland. Ph.D. Thesis, University of Auckland, Auckland, New Zealand. 161 pp.

Green, O.R. (1984a) New Zealand host and locality records for an introduced tortricid parasite, *Trigonospila brevifacies* (Diptera: Tachinidae). *New Zealand entomologist* 8, 69-71.

Green, O.R. (1984b) A diagnostic aid. *The Weta* 7(3), 65-67.

Helson, G.A. (1939) The oriental peach moth (*Cydia molesta* Busck). Investigations in the Goulburn Valley, Victoria. Progress report for 1935-8. *Council for Scientific and Industrial Research; Pamphlet* 88, 23 pp.

Kable, P.F. (1969) Brown rot of stone fruits on the Murrumbidgee irrigation areas. I – Aetiology of the disease in canning peaches. II - Aetiology of the disease in Trevatt apricot trees. *Australian journal of agricultural research* 20, 301-16 (Pt. I), 317-23 (Pt. II).

Luck, R.F. (1981) Parasitic insects introduced as biological control agents for arthropod pests. Pp. 125-184 in Pimentel, D. (ed.) *C.R.C. Handbook of pest management in agriculture* Vol. 2, C.R.C. Press, Florida.

MacLellan, C.R. (1973) Natural enemies of the light brown apple moth *Epiphyas postvittana*, in the Australian Capital Territory. *Canadian entomologist* 105, 681-700.

McLaren, I; Rye, W. (1981) Occurrence of *Trichogramma ivelae* Pang and Chen (Hymenoptera: Trichogrammatidae) and its use to control *Heliothis punctiger* Wallengren on tomatoes. *Journal of the Australian Entomological Society* 20, 110.

Miller, L.W. (1938) Codling moth and Williams pears. Goulburn Valley Investigations. *Journal of agriculture, Victoria* 36, 545-61, 572.

Russell, D.A. (1984) Oriental fruit moth – the Australian experience. *Orchardist of New Zealand* 57, 18-20.

Russell, D.A. (1986) Population dynamics of the oriental fruit moth (*Grapholita molesta* (Busck)) in New Zealand. Ph.D. Thesis, University of Auckland, Auckland, New Zealand.

Russell, D.A. (1987a) *Glabridorsum stokesii* (Cameron) (Hymenoptera: Ichneumonidae) – a parasitoid of the oriental fruit moth (*Grapholita molesta* (Busck)) in New Zealand. *New Zealand entomologist* 10, 26-38.

Russell, D.A. (1987b) Parasitism of the oriental fruit moth *Grapholita molesta* (Lepidoptera: Tortricidae): The New Zealand position in a world perspective. *New Zealand entomologist* 10, 13-26.

Russell, D.A. (1987c) A simple method for improving estimates of percentage parasitism by insect parasitoids from field sampling of hosts. *New Zealand entomologist* 10, 38-40.

Shaw, S.R. (1983) A taxonomic study of nearctic *Ascogaster* and a description of a new genus *Leptodrepana* (Hymenoptera: Braconidae). *Entomography* 2, 1-54.

Summers, F.M. (1966) The Oriental fruit moth in California. *University of California Agricultural Experimental Station extension service circular* 539.

Thomas, W.P. (1965) Studies on *Epiphyas postvittana* (Walker) (Lepidoptera, Tortricidae) and its parasitoid complex. M.Sc. Thesis, University of Canterbury, Christchurch, New Zealand. 130 pp.

Thomas, W.P. (1975) Additional notes on leafrollers. *Orchardist of New Zealand* 48, 354-355.

Thompson, W. (1946) A catalogue of the parasites and predators of insect pests. Section 1; Parasite host catalogue: Part 7; Parasites of the Lepidoptera (G-M): 259-385. Imperial Agricultural Bureaux, Belleville, Ontario, Canada.

Townes, H. (1969) Genera of Ichneumonidae; Part 2; Gelinae. *Memoirs of the American Entomological Institute* 12.

Valentine, E.W. (1967) A list of hosts of entomophagous insects. *New Zealand journal of science* 10, 1100-1210.

Valentine, E.W.; Walker, A.K. (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, in press.

Wearing, C.H. (1975) Integrated control of apple pests in New Zealand. 2- Field estimation of fifth-instar larval and pupal mortalities of codling moth by tagging with cobalt-58. *New Zealand journal of zoology* 2, 135-49.

Cydia pomonella (L.), codling moth (Lepidoptera: Tortricidae)

C.H. WEARING and J.G. CHARLES

Pest Status

The codling moth, *Cydia* (also known as *Carpocapsa, Enarmonia, Grapholita, Grapholitha,* or *Laspeyresia*) *pomonella* (L.), was accidentally introduced into New Zealand in the 1860s in apples imported from Tasmania and the United States (Miller 1953). Although a cosmopolitan pest today, codling moth originates from Eurasia and has spread to most temperate fruit-growing areas of the world, with the notable exception of Japan (Sheldeshova 1967). There are many other damaging *Cydia* species, but the only other one to reach New Zealand has been Oriental fruit moth, *Cydia* (= *Grapholita*) *molesta* (Busck) (see Chapter 28).

Codling moth is distributed throughout New Zealand and its main hosts are pip-fruits, such as apples and pears. Walnuts, plums, peaches, nectarines, and apricots are also attacked. The life cycle was described by Wearing (1984). The species is univoltine in the South Island and southern parts of the North Island, but with a small partial second generation in some seasons. In the north of the North Island there are two generations, and sometimes a partial third, each season. Codling moth overwinters as diapausing fifth instar larvae in cocoons, mainly under the bark and in crevices on its host tree. The larvae pupate in spring and summer and the emerging females mate and lay eggs close to, or on, developing fruits. The hatching larvae enter the fruits and, after moulting, bore into the centre where they complete development, only leaving the fruits again as mature fifth instar larvae to seek cocooning sites. Significant protection from natural enemies is provided by feeding within the fruit and by some cocooning sites (Wearing 1975b). The larvae also produce a defensive secretion (Bordas 1910).

Codling moth is a key pest of apples and pears. Because larvae directly damage the fruit, severe damage to the crop occurs every season in the absence of pesticides. Because fruit damage is not tolerated on export crops and is only slightly more acceptable on the domestic market, economic damage is caused even by very low densities of larvae which result from the presence of fewer than one mated female codling moth per tree. This limits the potential of natural enemies and diseases to provide economic control. Although codling moth is readily controlled by insecticides in New Zealand, it has become resistant to chemicals in other parts of the world (e.g. Madsen & Falcon 1960). Insecticide applications must be thorough and well timed to prevent damage in the northern regions of New Zealand where codling moth is bi- or multi-voltine.

Background

Codling moth has been extensively studied throughout the world (Butt 1975), including numerous investigations of its ecology and natural enemies (e.g. Geier 1964, Glen 1977, MacLellan 1977). In New Zealand, the ecology and population dynamics have been studied in Nelson (Wearing 1979) as a basis for the development of an integrated control programme (Collyer & van Geldermalsen 1975, Wood 1965). The natural enemies and pathogens attacking codling moth, which are endemic or have not been deliberately introduced to New Zealand, are listed in Table 29.1.

Mortality of the egg and first instar larval stages of codling moth is high in some apple growing areas of the world, particularly through predation (Glen 1977, MacLellan 1962).

Table 29.1 Natural enemies and pathogens of codling moth which are endemic to New Zealand or have not been deliberately introduced.

STAGE ATTACKED Species/Family	Nature of attack	Reference
EGG		
Sejanus (= *Idatiella*) *albisignata* (Knight) (Miridae)	Predation	Collyer & van Geldermalsen 1975, Wearing 1979, (see also Dumbleton 1938)
Anystis baccarum (L.) (= *A. agilis* (Banks) auct.) (Anystidae)	Predation	Collyer & van Geldermalsen 1975
Trichogramma sp. (Trichogrammatidae)	Parasitism	Wood 1965, Collyer & van Geldermalsen 1975, Wearing unpublished
Trichogramma ?minutum Riley	Parasitism	Valentine 1963
Trichogramma pretiosum Riley	Parasitism	Boucher 1902
FIRST INSTAR LARVA		
Sejanus (= *Idatiella*) *albisignata* (Knight) (Miridae)	Predation	Collyer & van Geldermalsen 1975, Wearing 1979, (see also Dumbleton 1938)
Anystis baccarum (L.) (= *A. agilis* (Banks) auct.) (Anystidae)	Predation	Wood 1965, Collyer & van Geldermalsen 1975 (see also MacLellan 1962)
LARVA IN FRUIT		
Beauveria sp. (Hyphomycetes)	Disease	Wearing 1975a, 1979
FIFTH INSTAR LARVA SEEKING COCOONING SITE		
Ixeuticus martius (Simon) (Amaurobiidae)	Predation	Wearing & Skilling 1975
FIFTH INSTAR LARVA IN COCOON		
Monomorium antarcticum (Smith) complex (Formicidae)	Predation	Wearing 1975b, 1979
Zosterops lateralis (Latham) (Zosteropidae)	Predation	Collyer & van Geldermalsen 1975, Wearing 1975a, 1975b, 1979
Sturnus vulgaris L. (Sturnidae)	Predation	Collyer & van Geldermalsen 1975, Wearing 1975a, 1979
Beauveria sp. (Hyphomycetes)	Disease	Collyer & van Geldermalsen 1975, Wearing 1975a, 1975b

Table 29.1 continued

STAGE ATTACKED Species/Family	Nature of attack	Reference
PUPA		
Beauveria sp. (Hyphomycetes)	Disease	Wearing 1975a
ALL STAGES LARVA TO ADULT		
Nosema carpocapsae (Microspora)	Disease	Malone & Wigley 1980, 1981a, 1981b

In New Zealand, parasitism of eggs by *Trichogramma* spp. may reach 17% on unsprayed trees (Wood 1965) but predation of both eggs and neonate larvae is very low (Collyer & van Geldermalsen 1975, Wearing 1979, Wood 1965). In addition to the identified predators (Table 29.1), earwigs may be predators of codling moth eggs as shown in England by Glen (1977). Earwigs (*Forficula auricularia* L.) are common in New Zealand apple orchards and are frequently found in the trees in fruit clusters (see Chapter 35). They were often observed among the fruit at the study site of Wearing (1979) and may have contributed to egg predation, albeit at low levels (Wearing unpublished). The low mortality of these young stages of codling moth led Wood (1965) to recommend introduction of predators for biological control.

No natural enemies have been recorded attacking codling moth larvae in the fruit in New Zealand, although low levels of fungal mortality have been observed (Table 29.1). The greatest natural mortality in the life cycle occurs to the fifth instar larvae, particularly when they are seeking cocooning sites after leaving the fruit (40-60%) and during overwintering in the cocoon (45-85%) (Wearing 1979). Mortality of larvae seeking cocooning sites has been attributed principally to invertebrate predators including spiders (Wearing 1975a, 1979) but only one species has been clearly identified (Table 29.1). Invertebrate predators are also thought to be responsible for the mortality of such wandering larvae in other parts of the world (Boyce 1941, Causse 1976, Geier 1963, Glen & Milsom 1978, Jaynes & Marucci 1947). Bird predation is the main cause of winter losses of larvae in cocoons in many localities (e.g. Glen & Milsom 1978, MacLellan 1958, 1959, Solomon *et al.* 1976), including New Zealand where the principal predator in Nelson is the immigrant Australian species *Zosterops lateralis* (Latham) (Wearing 1975a, 1975b, 1979). Birds caused an average of 53% mortality of larvae over five years in Nelson, with up to 90% mortality on some trees (Wearing 1975a). Fungi and ants are known to cause low overwintering losses (Table 29.1).

The main impact of the microsporidian disease of codling moth, *Nosema carpocapsae* Paillot, is probably on fecundity (Malone & Wigley 1981b) which is a key factor in the population dynamics of codling moth in Nelson (Wearing 1979). Other key factors include immigration and overwintering mortality, particularly that due to bird predation (Wearing 1979). As a result, reduction in the reservoirs of codling moth on unsprayed trees near orchards (such as through biological control) was seen by Wearing (1979) as important in the control of codling moth. However, augmentation of biological control by birds was seen as impractical, particularly as *Z. lateralis* also damages fruit crops.

Importations, Releases and Recoveries

Attempts to introduce natural enemies of codling moth were made by the New Zealand Department of Agriculture between 1890 and 1906, and again by the Cawthron Institute between 1931 and 1943. Entomology Division, DSIR imported predatory bugs from 1965 to 1967 and a parasitoid in the period 1969 to 1974. Details are given below and summarised in Table 29.2.

Table 29.2 Natural enemies introduced specifically for biological control of codling moth, with the synonyms under which they were imported into New Zealand and the numbers released

Species Synonyms (and references)	Period	Number released
NEUROPTERA: RAPHIDIIDAE		
Raphidia sp.	1890-91	'few'
HYMENOPTERA: BRACONIDAE		
Ascogaster quadridentata Wesmael		
A. carpocapsae Viereck (DSIR files)	1931-32	814
Phanerotoma fasciata Provancher		
P. tibialis auct. (DSIR files)	1932-34	1 escape
HYMENOPTERA: ICHNEUMONIDAE		
Liotryphon caudatus (Ratzeburg)		
Calliephialtes messor (Gravenhorst) (Ann. rep. N.Z. Dep. Agric. 1907, 1908, 1909)	1906 1907	6 'colonies' Supplied to 69 orchards*
Ephialtes messor Gravenhorst (Dumbleton 1936)	1942	c. 450
Ephialtes caudatus Ratzeburg (Ann. rep. Cawthron Inst. 1942, DSIR files)	1944	Not known*
Apistephialtes caudatus (Ratzeburg) (Valentine 1967)		
Mastrus carpocapsae (Cushman)		
Aenoplex carpocapsae Cushman (Ann. rep. Cawthron Inst. 1943-44)	1943-44	fewer than 80
Aenoplex carpocapsas (sic) (Ann. rep. Cawthron Inst. 1944-45)		
Cryptus sexannulatus Gravenhorst	1942-44	Not known* (if any)

*Numbers not known

Predators

Raphidia sp. (Neuroptera: Raphidiidae)

R.A. Wight, a New Zealand orchardist and amateur entomologist, arranged for A. Koebele to send some codling moth 'parasites' from California (Anonymous 1890, Wight 1890a). A shipment arrived in New Zealand in April 1890, consisting of 21 individually packaged *Raphidia* sp. larvae. They were intercepted by New Zealand customs officials, opened and detained for 10 days for 'examination' before being forwarded to Wight. On receipt, he found 16 pupae and one larva in 17 boxes (Wight 1890b). He reared these *Raphidia* sp. and observed the larva to kill and eat codling moth larvae. He concluded that they would be useful to New Zealand, but recognised that importations on a larger scale would be needed. He released the 'few flies he had succeeded in rearing from the breeding cages' sometime in late 1890 or January 1891 (Wight 1891).

A further shipment of *Raphidia* sp. (only six larvae) was brought to New Zealand by Koebele on his second visit in 1891. Although they arrived in 'good health' (Anonymous 1891), their fate is not known. Wight may have sent 'a few of them' to Australia for 'acclimatisation' (Anonymous 1892).

These are the first recorded attempts anywhere in the world to control codling moth by the importation of natural enemies (Clausen 1978).

Predatory bugs (Hemiptera: Anthocoridae, Miridae)

In the period 1965 to 1967, E. Collyer organised the introduction of two species of anthocorids, *Anthocoris nemorum* (L.) and *A. musculus* (Say), and two species of mirids, *Blepharidopterus angulatus* (Fallén) and *Hyaliodes harti* Knight, for the control of European red mite (see Chapter 38). These predators came from England and Nova Scotia but failed to become established (Collyer & van Geldermalsen 1975). *A. nemorum* feeds on lepidopterous larvae (Collyer 1967) and was shown by Glen (1977) to feed on codling moth eggs in the laboratory. *B. angulatus* and *H. harti* are known predators of codling moth eggs and young larvae (Glen 1977, MacLellan 1962).

Parasitoids

Liotryphon caudatus (Ratzeburg) (Hymenoptera: Ichneumonidae)

Synonyms for this species in New Zealand are listed in Table 29.2. *L. caudatus* was introduced into California from Spain in 1904-5 (Clausen 1978). By 1906 it had been released into a few properties in California, with 'hopeful results', but was still being reared in captivity for commercial sale. New Zealand was able to obtain a laboratory-reared colony from the California State Board of Horticulture in exchange for supplies of codling moth larvae, which were then in short supply in California, for their rearing programme (Kirk 1907).

L. caudatus (in codling moth cocoons) were brought to New Zealand by W.A. Boucher of the New Zealand Department of Agriculture in 1906 (some time between April and September). The population was increased in the insectary. When supplies of codling moth cocoons became exhausted releases were made, the first in early December 1906. Six different growers were each sent one colony (Kirk 1907). Recoveries of *L. caudatus* from codling moth cocoons were made in June 1907 from two of these orchards (Boucher 1908). Further parasitoids were reared during the following winter, and released the next season to 69 orchards throughout New Zealand.

The following year was considered too early to report on the value of *L. caudatus* as a control measure, but 'the outlook is certainly hopeful' (Kirk 1909).

Over 20 years later *L. caudatus* was known to occur only in the Auckland Province, where it was not considered an important factor in codling moth control (Dumbleton 1936).

A further shipment of 200 *L. caudatus* larvae was received by the Cawthron Institute on 10 May 1942 from Canada. Surviving adults were mated, and the first generation reared in New Zealand yielded 103 adults (73 males and 30 females) during October-November 1942 (DSIR files). These were mated, and 592 parasitoid larvae reared. From these, 480 adults (402 males and 78 females) developed. Most of these were liberated in three abandoned orchards (presumably in Nelson), but sufficient female parasitoids were retained for continued breeding (Anonymous 1942). Further releases were made in February 1944 (Anonymous 1944).

Despite careful inspections during the 1944-45 season in two of the release orchards, no trace of the parasitoid was found (Anonymous 1945).

Both Dumbleton (1936) and Valentine (1967) reported that *L. caudatus* was known only from Auckland. However, in 1971 a mated female collected in Hamilton was used to begin a rearing colony at Entomology Division, DSIR, Nelson. Forty adults were released at Appleby Research Orchard into unsprayed apple trees (L. Skilling DSIR files) in the spring and early summer of 1971 but no recoveries were made and there was no known establishment

in the area. Wearing (unpublished) recorded a single codling moth larva in its cocoon parasitised by *L. caudatus* at Havelock North Research Orchard, Hawke's Bay in 1975. The current known distribution of the species is, therefore, Auckland, Waikato and Hawke's Bay.

Mastrus carpocapsae (Cushman) (Hymenoptera: Ichneumonidae)

Synonyms for this species in New Zealand are listed in Table 29.2. A consignment of *M. carpocapsae* (54 adults, 67 larvae and 51 pupae) arrived by air from Canada on 13 March 1943. By March 1944, 80 adult *M. carpocapsae* had been reared, at least some of which were liberated (Anonymous 1944, 1945), presumably in, or close to, Nelson. No recoveries were made (Anonymous 1946).

Cryptus sexannulatus Gravenhorst (Hymenoptera: Ichneumonidae)

C. sexannulatus (46 adults, 19 larvae, nine pupae) were received from Canada on 13 March 1942. These were reared and by March 1944 there were 119 adult parasitoids. However, there are no records of any releases.

Phanerotoma fasciata Provancher (Hymenoptera: Braconidae)

This species has been referred to as *P. tibialis* in DSIR files (Table 29.2). By 1931, the control of codling moth in New Zealand was considered to be of very high priority. In 1930, while travelling extensively abroad, D. Miller gave special attention to codling moth, and arranged for shipments of parasitoids from Farnham Royal and from the U.S.A. (DSIR files).

Two shipments of *P. fasciata* arrived in New Zealand, from Albany, Georgia, U.S.A. via Los Angeles. The first shipment consisted of 40 codling moth larvae which had been earlier exposed to *P. fasciata*, which oviposits in codling moth eggs, but emerges from the cocooned larvae.

Thirty-nine larvae arrived alive on 7 December 1932. On 16 December, four were dissected and found not to be parasitised. Twenty-one moths had emerged by the end of January 1933, and no parasitoids were obtained (DSIR files).

The second shipment arrived at the Cawthron Institute on 2 January 1934. About 140 codling moth larvae were received, but 137 either died or transformed to adults. Only three *P. fasciata* emerged, all females. Two were allowed to oviposit (unmated) in codling moth eggs and the third escaped (DSIR files). A few male progeny were reared from these eggs (DSIR files), but there were no releases (Dumbleton 1936).

Glabridorsum (= *Gambrus* = *Ischnus*) *stokesii* (Cameron) (Hymenoptera: Ichneumonidae)

G. stokesii was introduced to New Zealand against lightbrown apple moth, *Epiphyas postvittana* (Walker) (see Chapter 33).

G. stokesii has been known as a parasitoid of codling moth in Australia for many years (Helson 1939, Miller 1938). Geier (1964) found that *G. stokesii* parasitises fifth instar larvae of codling moth after ovipositing on the mature larvae in their cocoons. However, in his intensive study of codling moth population dynamics in the Australian Capital Territory, Geier never found *G. stokesii* associated with codling moth pupae in spring and concluded that there was no association with this host over the winter. *G. stokesii* has several tortricid hosts (see Chapters 28, 33).

Despite becoming well established in New Zealand, *G. stokesii* has been observed to oviposit on codling moth cocoons only in Nelson (Collyer & van Geldermalsen 1975) and no clear evidence of parasitism of the species has been obtained. In view of the results of Geier (1964), the best prospects for this species attacking codling moth may be in the northern regions of the country where codling moth is bivoltine/multivoltine.

Ascogaster quadridentata Wesmael (Hymenoptera: Braconidae)

This species has been referred to as *A. carpocapsae* in DSIR files (Table 29.2). About 700 parasitised codling moth larvae arrived at the Cawthron Institute from Farnham Royal on 6 January 1931. 600 were stored at 4°C until spring so that codling moth eggs would be available for emerging adults to parasitise. Twelve *A. quadridentata* emerged from the remaining 100 larvae in March/April 1931, but they all died because there were no codling moth eggs available for oviposition. Two hundred and eight *A. quadridentata* emerged from the 600 larvae between November 1931 and January 1932 (but mostly from 23 November to 5 December 1931). A second shipment of 1,371 parasitised codling moth larvae from Farnham Royal arrived at the Cawthron Institute on 25 August 1931.

Releases from these two shipments were made between December 1931 and January 1932 as follows: 150 were sent to Hawke's Bay, 125 sent to Auckland, 524 (mostly from the second shipment) were liberated in Nelson, and 15 were released in Murchison (DSIR files). The procedures used to determine whether these releases were successful have not been recorded and Dumbleton (1936) reported that establishment was not known.

A third shipment of *A. quadridentata* was received by air from Canada at the Cawthron Institute during 1942. The adults which emerged failed to survive until codling moth eggs were available in the following spring.

A. quadridentata is now established in New Zealand (Valentine 1963), presumably from the introductions of 1931-32. It was collected by W. Cottier in derelict orchards in Nelson during the 1950s (W.P. Thomas unpublished).

Evaluation

L. caudatus is known to be established in Auckland, Waikato and Hawke's Bay but with very little impact on codling moth populations.

Collyer & van Geldermalsen (1975) reported 26% and 7% of larvae parasitised by *A. quadridentata* respectively in 1963-64 and 1964-65 at Mapua, Nelson. Tomkins *et al.* (1987) found in Canterbury that 17% of larvae (range 5.7 to 32.2%) entering corrugated cardboard bands to cocoon had been parasitised. Collyer & van Geldermalsen (1975) found less than 2% of larvae parasitised at Appleby Research Orchard, Nelson, but Wearing (1979) recorded no parasitism by *A. quadridentata* there over several seasons, despite its being common in overwintering larvae from unsprayed trees in the district (up to 30%, Wearing unpublished).

A. quadridentata parasitises the egg of codling moth and develops throughout the larval period of the host, finally emerging from the host larval cocoon (in the following spring in univoltine areas). The parasitised fifth instar larvae are characteristically small. This parasitoid has not reduced the key pest status of codling moth and provides little protection to the fruit from damage.

Conclusions

The ability of codling moth to inflict economic damage at very low population density has discouraged any recent attempts at biological control. New Zealand apple production is principally for export and must meet stringent pest-free quarantine requirements. Nevertheless, study of the population dynamics of codling moth in univoltine areas such as Nelson has shown that only a small increase in generation mortality is required to reduce the population density from year to year (Wearing 1979). Integrated control, which combines natural mortality with selective insecticides, granulosis virus, male removal by pheromone traps, or mating disruption (Moffitt *et al.* 1982, Wearing 1979), has received greater emphasis than biological control in an attempt to meet both export and general pest control requirements. Home gardeners, producers of 'organic' fruit, and orchardists who sell their fruit 'at the gate' have received limited benefit from the introductions of natural enemies so far undertaken and would benefit most from further introductions. However, there are no known outstanding candidates and all fruitgrowers are more likely to benefit from the

development of selective and integrated control methods, such as those based on the granulosis virus and/or sex pheromone of codling moth.

Wearing (1979) showed the importance of immigration of adult moths in the population dynamics of codling moth. This is particularly important for commercial growers who aim to reduce populations to extremely low levels within the orchard. Treatment or removal of unsprayed infested trees in the environs of orchards is probably more economic than the introduction of biological control agents to reduce these reservoirs.

Literature Cited

Anonymous (1890) Sending codling moth enemies from the United States to New Zealand. *Insect life* 3, 43.

Anonymous (1891) Insect police from America. *New Zealand farmer*, October, 414.

Anonymous (1892) *Raphidia* in New Zealand. *Insect life* 4, 339.

Anonymous (1942) Entomological investigations. Codlin-moth parasites. *Annual report of the Cawthron Institute for 1942*, 25.

Anonymous (1944) Fruit research. Codlin-moth parasites. *Annual report of the Cawthron Institute for 1943-44*, 17.

Anonymous (1945) Fruit research. Codlin-moth parasites. *Annual report of the Cawthron Institute for 1944-45*, 18.

Anonymous (1946) Fruit research. Insect pests. *Annual report of the Cawthron Institute for 1945-46*, 18.

Bordas, M.L. (1910) Les glandes céphaliques (glandes sericigènes et glandes mandibulaires) des chenilles de lepidoptères. *Annales des Sciences naturelles de zoologie et biologie animale* (9) 10, 125-198.

Boucher, W.A. (1902) Report. *Report of the New Zealand Department of Agriculture for 1902*, 433-434.

Boucher, W.A. (1908) Report. *Report of the New Zealand Department of Agriculture for 1908*, 128-134.

Boyce, H.R. (1941) Biological control of the codling moth in Ontario. *Annual report of the Ontario Entomological Society* 71 (1940), 40-44.

Butt, B.A. (1975) Bibliography of the codling moth. *USDA bulletin* ARS W-31, 221 pp.

Causse, R. (1976) Étude de la localisation et de la mortalité hivernale des larves de *Laspeyresia pomonella* L. (Lepidoptera, Tortricidae) en vergers modernes de pommiers de la basse vallée du Rhône. *Annales de zoologie ecologie animale* 8, 83-101.

Clausen, C.P. (1978) (ed.) Introduced parasites and predators of arthropod pests and weeds. A world review. *USDA, ARS, Agricultural Handbook* 480, 545 pp.

Collyer, E. (1967) On the ecology of *Anthocoris nemorum* (L.) (Hemiptera: Heteroptera). *Proceedings of the Royal Entomological Society of London (A)* 42, 107-118.

Collyer, E.; van Geldermalsen, M. (1975) Integrated control of apple pests in New Zealand. 1. Outline of experiment and general results. *New Zealand journal of zoology* 2, 101-134.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1936) Biological control of noxious insects and weeds in New Zealand. IV. The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 579-593.

Dumbleton, L.J. (1938) Notes on a new mirid bug (*Idatiella albisignata* Knight). *New Zealand journal of science and technology* 20, 58B-60B.

Geier, P.W. (1963) The life history of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) in the Australian Capital Territory. *Australian journal of zoology* 11, 323-367.

Geier, P.W. (1964) Population dynamics of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) in southeastern Australia. *Australian journal of zoology* 12, 381-416.

Glen, D.M. (1977) Predation of codling moth eggs *Cydia pomonella*, the predators responsible and their alternative prey. *Journal of applied ecology* 14, 445-456.

Glen, D.M.; Milsom, N.F. (1978) Survival of mature larvae of codling moth (*Cydia pomonella*) on apple trees and ground. *Annals of applied biology* 90, 133-146.

Helson, G.A. (1939) The oriental peach moth (*Cydia molesta* Busck). Investigations in the Goulburn Valley, Victoria. *Progress report for 1935-38. Council for Scientific and Industrial Research; Pamphlet* 88, 23 pp.

Jaynes, H.A.; Marucci, P.E. (1947) Effects of artificial control practices on the parasites and predators of the codling moth. *Journal of economic entomology* 40, 9-25.

Kirk, T.W. (1907) Annual Report: fruit industry prospects and progress. *Report of the New Zealand Department of Agriculture for 1907*, 206-212.

Kirk, T.W. (1909) Annual Report: principal insects of the year. *Annual report of the New Zealand Department of Agriculture for 1909*, 86-88.

MacLellan, C.R. (1958) Role of woodpeckers in control of codling moth in Nova Scotia. *Canadian entomologist* 90, 18-22.

MacLellan, C.R. (1959) Woodpeckers as predators of the codling moth in Nova Scotia. *Canadian entomologist* 91, 673-680.

MacLellan, C.R. (1962) Mortality of codling moth eggs and young larvae in an integrated control orchard. *Canadian entomologist* 94, 655-666.

MacLellan, C.R. (1977) Trends of codling moth (Lepidoptera, Olethreutidae) populations over 12 years on two cultivars in an insecticide-free orchard. *Canadian entomologist* 109, 1555-1562.

Madsen, H.F.; Falcon, L.A. (1960) DDT-resistant codling moth on pears in California. *Journal of economic entomology* 53, 1083-1085.

Malone, L.A.; Wigley, P.W. (1980) The distribution of *Nosema carpocapsae*, a protozoan pathogen of the codling moth *Cydia pomonella* (Lepidoptera: Tortricidae) in New Zealand. *New Zealand entomologist* 7, 151-153.

Malone, L.A.; Wigley, P.W. (1981a) The morphology and development of *Nosema carpocapsae*, a microsporidian pathogen of the codling moth, *Cydia pomonella* (Lepidoptera: Tortricidae) in New Zealand. *Journal of invertebrate pathology* 38, 315-329.

Malone, L.A.; Wigley, P.W. (1981b) Quantitative studies in the pathogenicity of *Nosema carpocapsae*, a microsporidian pathogen of codling moth, *Cydia pomonella*, in New Zealand. *Journal of invertebrate pathology* 38, 330-334.

Miller, D. (1953) Historical review of New Zealand entomology. *Report of the Seventh Science Congress, Royal Society of New Zealand, Christchurch, 1951*, 80-86.

Miller, L.W. (1938) Codling moth and Williams pears. Goulburn Valley investigations. *Journal of agriculture, Victoria* 36(11), 545-561, 572.

Moffitt, H.R.; Wearing, C.H.; Clearwater, J.R. (1982) Suppression of codling moth populations through mating disruption with the sex pheromone. Pp. 98-102 in Galbreath, R.A. (ed.) Insect pheromones and their application. *DSIR Entomology Division report* 2, 120 pp.

Sheldeshova, G.G. (1967) Ecological factors determining the distribution of the codling moth *Laspeyresia pomonella* L. (Lepidoptera, Tortricidae) in the northern and southern hemispheres. *Entomological review* 46, 349-361.

Solomon, M.E.; Glen, D.M.; Kendall, D.A.; Milsom, N.F. (1976) Predation of overwintering larvae of codling moth (*Cydia pomonella* (L.)) by birds. *Journal of applied ecology* 13, 341-352.

Tomkins, A.R.; Penman, D.R.; Chapman, R.B. (1987) Overwintering of codling moth larvae in an abandoned Canterbury apple orchard. *New Zealand entomologist* 10, 40-44.

Valentine, E.W. (1963) Integration of biological and chemical methods of pest control. *New Zealand science review* 22, 14-16.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Wearing, C.H. (1975a) Integrated control of apple pests in New Zealand. 2. Field estimation of fifth-instar larval and pupal mortalities of codling moth by tagging with cobalt-58. *New Zealand journal of zoology* 2, 135-149.

Wearing, C.H. (1975b) Integrated control of apple pests in New Zealand. 3. Natural mortality of fifth-instar larvae of codling moth tagged with cobalt-58 in relation to their distribution. *New Zealand journal of zoology* 2, 151-168.

Wearing, C.H. (1979) Integrated control of apple pests in New Zealand. 10. Population dynamics of codling moth in Nelson. *New Zealand journal of zoology* 6, 165-199.

Wearing, C.H. (1984) Codling moth, *Cydia pomonella* (Linnaeus) life cycle. *DSIR Information Series* No. 105/8, 1st Revision, 4 pp.

Wearing, C.H.; Skilling, L. (1975) Integrated control of apple pests in New Zealand. 4. Survival of fifth-instar larvae of codling moth on the ground. *New Zealand journal of zoology* 2, 245-255.

Wight, R.A. (1890a) Codlin moth parasites. *New Zealand farmer* January, 10.

Wight, R.A. (1890b) Enemies of the codlin moth. *New Zealand farmer* June, 206.

Wight, R.A. (1891) The new parasite on the codlin moth. *New Zealand farmer* February, 52.

Wood, T.G. (1965) Field observations on flight and oviposition of codling moth (*Carpocapsa pomonella* (L.)) and mortality of eggs and first-instar larvae in an integrated control orchard. *New Zealand journal of agricultural research* 8, 1043-1059.

Dasineura pyri (Bouché), pear leafcurling midge and *Dasineura mali* (Kieffer), apple leafcurling midge (Diptera: Cecidomyiidae)

J.A. BERRY and J.T.S. WALKER

Pest Status

The pear leafcurling midge *Dasineura* (= *Perrisia*) *pyri* (Bouché) is known as a minor pest of pear trees throughout Europe and has been present in North America since 1929 (Barnes 1948). It was first recorded in New Zealand in the spring of 1916 at Avondale, Auckland and had spread through most pear growing regions by 1925 (Miller 1925).

Dasineura mali (Kieffer), the apple leafcurling midge is found in Europe and North and South America. In New Zealand, it was first recorded in 1950 in Auckland, probably from infested apple stocks from Holland (Morrison 1953), and is now quite widespread on apple trees throughout New Zealand (Penman 1984).

The adult females of both *Dasineura* spp. oviposit between the folds of immature leaves. As a result of larval feeding, the leaf margins become tightly curled. The infested leafcurl may redden, then become brown and brittle, finally dropping from the tree. The terminal shoots are stunted as a result. Some larvae pupate in the rolled leaves and others drop to the ground, where they may overwinter to emerge as adults from late September onwards.

Miller (1921) reported six generations of *D. pyri* in the 1920-1921 season, causing 'extensive devastation' to the point where it was impossible to grow young pear trees or nursery stock. Adamson (1935) reported *D. pyri* as a pest of considerable economic importance on young trees, and more particularly on new grafts. There is no information available about present levels of damage due to *D. pyri*.

The life cycle of *D. mali* is essentially similar to that of *D. pyri*, although larval and pupal stages are slightly longer (Todd 1956) and Penman (1984) reported up to five generations per year. Todd (1956) reported severe stunting of *D. mali*-infested apple trees but no noticeable reduction in abundance of fruit. Mature trees are able to withstand considerable damage from apple leafcurling midge but young trees can be permanently damaged (Penman 1984).

Background

Miller (1921) reported that no parasitoids of *D. pyri* had been reared from hosts collected in New Zealand, though he noted several predators. *Chrysosoma mobile* (Hutton) (Diptera: Dolichopodidae) (as *Psilopus mobilus*) a native fly, and a native damsel fly *Austrolestes colensonis* (White) (Odonata: Lestidae) were both observed feeding on adult midges. An unidentified coccinellid was an effective predator in the laboratory and was often found in association with *D. pyri* in infested soil. A small epeirid spider was also a common predator of the midge.

In view of the lack of native parasitoids, importation of natural enemies from Europe was proposed, but prior to 1925 little was known about their occurrence. In 1918, Mercet (1917) was reported to have reared *Inostemma piricola* Kieffer (Hymenoptera: Platygasteridae) from *D. pyri* and it was suggested that *I. piricola* be imported for establishment in New Zealand (Miller 1926). In fact, this record was incorrect according to Myers (1927) who had referred to the original paper by Mercet and discovered that the host was *Contarinia pyrivora* (Riley), the pear midge, not *D. pyri*. On the basis of this misinformation, control agents

were first sought in Europe in 1925 by collecting parasitised *C. pyrivora* for export to New Zealand.

Later that year, in France, Ferrière (1927) reared the following parasitic Hymenoptera from *D. pyri*: *Inostemma boscii* (Jurine) (Platygasteridae); *Platygaster demades* (Walker) (Platygasteridae) and *Torymus chloromerus* (Walker) (Torymidae). A diapriid and several other chalcids were reared in very small numbers. Parasitised *D. pyri* material was exported to New Zealand in the expectation that *I. boscii* would be the main parasitoid to emerge (Miller 1926). In fact there is no record of *I. boscii* emerging from this material (except Clausen (1978), probably erroneously), or of its release in New Zealand. However, in 1938, a specimen was collected from Henderson (Dumbleton 1964), so it is possible that *I. boscii* was reared from the European material and released inadvertently. In any case, *Platygaster demades* emerged in much greater numbers and the release programme was centred on this species.

Importations, Releases and Recoveries

Nomenclature

The current name of the parasitoid introduced in 1925 for the control of *Dasineura pyri* is *Platygaster demades* (Kloet & Hincks 1978, Vlug & De V. Graham 1984). When first recorded from *D. pyri* by Fisher in 1925, *P. demades* was identified as *Platygaster* sp. and was referred to as such by Miller (1926) and Fisher (1927).

Ferrière (1927) identified *P. demades* as *Misocyclops marchali* (Kieffer), and Myers (1927), Miller (1928) and Muggeridge (1929) refer to *P. demades* as *M. marchali*. Dumbleton (1934) reported on the examination of *P. demades* larvae and concluded they were more likely to be *Misocyclops ornatus* Kieffer, a name also used by Sweetman (1935). Dumbleton submitted some adults to the then Imperial Institute of Entomology (I.I.E.) to check the identification, and staff there were of the opinion that the specimens were either *M. marchali* or a new species of *Misocyclops* (Dumbleton 1935). Dumbleton seems to have accepted *M. marchali* because Miller *et al.* (1936) reverted to using that name.

In 1956, D.H.Todd sent *P. demades* specimens reared from *Dasineura mali* to the Commonwealth Institute of Entomology (CIE) where G.E.J.Nixon identified them as *Prosactogaster demades* (Walker), stating that this name had priority over *Misocyclops marchali* (Todd 1956). This name was used by Todd (1956, 1959) and Cameron *et al.* (1987).

Clausen (1978) referred to *Platygaster demades* but also listed as agents brought into New Zealand for biological control of *D. pyri* the synonyms *Misocyclops* sp. and *M. marchali*. Valentine & Walker (1989) use *Platygaster demades* Walker.

Consignments in 1925

The first consignment of *Contarinia pyrivora*-infested pear fruit was collected in France (locality unspecified) in 1925 by R.C. Fisher at the instigation of the New Zealand Department of Agriculture, in the hope of rearing *Inostemma piricola*. It was sent in cool storage, as was all subsequent material, and on receipt was placed in emergence boxes in a specifically designed 'insectary' constructed over a midge infested pear tree in Henderson, Auckland. No parasitoids emerged from this consignment, nor did any *C. pyrivora*.

J.G. Myers collected the second consignment near Paris. It consisted of *D. pyri*-infested leaves from which *Platygaster demades*, *Torymus chloromerus* and *Inostemma boscii* had been reared. In the Henderson insectary, 41 female and 21 male *P. demades* emerged, along with *D. pyri* and another unidentified species of midge. Fifteen female and six male *P. demades* were released in the orchard at Henderson and 25 females and six males were released in the insectary.

This was the first release of *P. demades* in New Zealand. Other insects to emerge were an unidentified ichneumonid, which was killed, several predaceous beetle larvae and one *T. chloromerus*. The fates of the latter were unspecified.

The third consignment was collected by Fisher, who sent a small amount of pear material infested by 'midges'. Five female and three male *P. demades* emerged and these were liberated in the insectary.

The *P. demades* from the second consignment, which were liberated in the insectary, were seen to oviposit into *D. pyri* eggs. When these eggs hatched they were placed in a rearing box and a month later four male *P. demades* emerged. The parasitoids liberated in the orchard were also seen to oviposit in *D. pyri*-infested leaves. The 1925 importations and releases are detailed by Miller (1925).

Consignments in 1926 In 1926 Fisher sent five consignments of parasitised *D. pyri* to New Zealand; one from England, three from France and one originating from both countries (Fisher 1927). The following insects emerged from these consignments: *P. demades*, in unspecified numbers; 18 predatory capsids, *Pilophorus perplexus* Douglas & Scott (Hemiptera: Miridae); and 12 *T. chloromerus*. *Platygaster demades* emerged in greater numbers than from the 1925 consignments (Miller 1927). Miller did not document releases from the 1926 consignments, but commented (1928) that establishment was able to be carried out on a sufficiently large scale with these. Muggeridge (1929) reported that the material was used mainly to ensure establishment of the parasitoid so presumably much of it was released from late 1926 to early 1927, although there are only incomplete records of the localities (DSIR files).

Recoveries from *Dasineura pyri*

In the autumn of 1927, *P. demades* was recovered in Henderson orchards 'where liberations had been made earlier in the season' (Miller 1928). These 'liberations' must have been adults from the 1926 consignments, released in the summer of 1926. *P. demades* successfully overwintered in 1927 (Muggeridge 1929), and in spring 1927, Miller (1928) noted 'a very decided increase of parasites in the field' correlated with a marked improvement in the health of the trees and a decrease in midge infestation.

In spring 1926, three female and one male *P. demades* were released in an orchard in Stoke, Nelson, and the species was found to be present there 15 months later (Miller 1928). Miller considered *P. demades* to be well established at Henderson and at Stoke by the end of 1927.

In December 1927, midge-infested foliage was distributed to various growers (Miller 1928, Muggeridge 1929), and the following year, the orchards which had received this material were surveyed. Recoveries were made in several orchards in Auckland but nowhere else, and levels of parasitism were very low. Muggeridge (1929) records areas to which parasitised material was sent and recovery figures.

No further introductions of biological control agents against *D. pyri* were made.

Recoveries from *Dasineura mali*

No control agents were ever imported against *D. mali*, but in 1954 parasitism by *P. demades* was first observed in a Palmerston North orchard with levels ranging from 27% to 66% (Todd 1956). The parasitoid was also reported present in Nelson by Collyer & Geldermalson (1975).

Evaluation

Dasineura pyri

Muggeridge (1929) concluded that *P. demades* provided an unsatisfactory degree of control of *D. pyri* and continually urged for a study to be made of the ecology of the predatory

capsid, *Pilophorus perplexus* (DSIR files). He also recommended that *T. chloromerus* be imported. These recommendations were endorsed by the authorities in New Zealand, who approached I.I.E. for assistance but the work was never carried out (DSIR files).

Other researchers considered that *Platygaster demades* exerted a significant level of control once established. Dumbleton (1934) considered that *P. demades* was exercising a very useful degree of control over the pest, and in the 1933-1934 season found up to 33% parasitism in Nelson and up to 83% in Henderson (Dumbleton 1935). Sweetman (1935) listed *P. demades* as a successful example of biological control. However, *D. pyri* populations continued to reach damaging levels in all areas. Dumbleton (1935) postulated that this was because the life cycle of *P. demades* was not synchronized with that of *D. pyri*, the first parasitoids not emerging early enough to limit numbers of the first *D. pyri* generation.

Dasineura mali

Todd (1959) studied levels of parasitism for three consecutive seasons in an apple orchard in Palmerston North and found that despite these being generally high, *D. mali* populations continued to reach damaging levels. In each season *P. demades* was almost entirely absent when the second generation of *D. mali* began, allowing a significant population build up. Percentage parasitism in later generations was high but population levels of *D. mali* were also high. Todd considered that the absence of *P. demades* from the second generation showed clearly that the parasitoid generations were not synchronised with that of its host.

Collyer & Geldermalsen (1975) reported damage to apple trees in a Nelson orchard in some seasons, despite the presence of *P. demades*. In a neighbouring, completely unsprayed orchard, *D. mali* continued to cause considerable damage despite the presence of *P. demades* over many years.

Conclusions

Platygaster demades has been established in New Zealand for half a century and has been reported from all apple and pear-growing regions. Evidence from field studies suggests that a lack of synchronization between the life cycle of this parasitoid and that of either of its hosts precludes the possibility of highly effective control in New Zealand. Although there are no records of *Inostemma boscii* being released in New Zealand, a single specimen was collected in Henderson in 1938, where the original imported material had been reared nearly ten years previously. Further specimens have been collected in 1981 from Kumeu and Mt Albert, (by E.W.Valentine and deposited in the New Zealand Arthropod Collection), though none have host records. Thus, *I. boscii* would appear to have established but there is too little information available to speculate about its impact on *Dasineura* spp. populations. The chalcidoid *Torymus chloromerus* was probably not released. It has not been recorded from New Zealand and would be a candidate for further study should the introduction of other control agents against *Dasineura* species be considered necessary. Little has been published in recent years about the pest status of *D. pyri* or *D. mali*, suggesting that neither is a pest of major importance. Eade (1974) mentioned that a carbofuran spray schedule aimed at control of leafrollers, mealybugs and mites on various fruit crops was effective in controlling *D. pyri*. Collyer & Geldermalsen (1975) reported considerable damage to unsprayed apple trees in a Nelson orchard, compared to fewer problems in an adjacent sprayed orchard. It is probable that spray schedules aimed at more serious pests are keeping leafcurling midge largely under control.

Acknowledgements

We thank T.K. Crosby (DSIR) for discussion on changes in nomenclature and A.K. Walker (CIE) for confirming the current name of the control agent.

Literature Cited

Adamson, N.J. (1935) Protection of pear grafts from the pear-leaf-curling midge. *New Zealand journal of agriculture* 50, 43-44.

Barnes, H.F. (1948) Gall midges of economic importance. Volume 3. Crosby Lockwood, London. 184 pp.

Cameron, P.J; Hill, R.L; Valentine, E.W; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of pests and weeds, for pollination, and for dung dispersal from 1874 to 1985. *DSIR Bulletin* 242, 51 pp.

Clausen, C.P. (ed.) (1978) Introduced parasites and predators of arthropod pests and weeds: a world review. *United States Department of Agriculture handbook* 480. 545pp.

Collyer, E; Geldermalsen, M. van (1975) Integrated control of apple pests in New Zealand.1. Outline of experiment and general results. *New Zealand journal of zoology* 2, 101-134.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1934) Note on pear midge parasite. *New Zealand journal of science and technology* 16, 339-341.

Dumbleton, L.J. (1935) Further note on pear midge parasite. *New Zealand journal of science and technology* 16, 339-341.

Dumbleton, L.J. (1964) Notes on insects. *New Zealand entomologist* 3(3), 24-25.

Eade, R.P. (1974) Control of fruit pests with carbofuran. *Proceedings of the 27th New Zealand weed and pest control conference* 27, 147-152.

Ferrière, C. (1927) Parasites de *Perrisia pyri*, Bouché (Dipt., Cecidom.) *Bulletin of entomological research* 17, 421-422.

Fisher, R.C. (1927) Parasites of the pear midge (*Perrisia pyri*). Collection of material in France 1926. *New Zealand journal of agriculture* 35, 107-111.

Kloet, G.S; Hincks W.D. (1978) A check list of British insects. Handbooks for the identification of British insects, Vol.11 Part 4: Hymenoptera. Royal Entomological Society of London. 159 pp.

Mercet, R.G. (1917) Microhimenópteros de España utiles à la agricultura. *Asociación Española para e progresso di las ciencias, Congreso de Valladolid* sección 4a, 367-377 (English abstract only seen, reported in *Review of applied entomology A* (1918) 6, 113).

Miller, D. (1921) The pear leaf-curling midge. Notes on the Auckland infestation. *New Zealand journal of agriculture* 23, 84-92.

Miller, D. (1925) The pear-midge. Further observations and control with calcium cyanide. *New Zealand journal of agriculture* 30, 220-224.

Miller, D. (1926) Parasites of the pear-midge (*Perrisia pyri*). First attempt at their establishment in New Zealand. *New Zealand journal of agriculture* 32, 379-393.

Miller, D. (1927) Parasites of the pear midge (*Perrisia pyri*). Report on the 1926 consignments from Europe. *New Zealand journal of agriculture* 35, 170-175.

Miller, D. (1928) Establishment of beneficial insects in New Zealand. *New Zealand journal of agriculture* 37, 193-195.

Miller, D.; Clark, A.F.; Dumbleton, L.J. (1936) Biological control of noxious insects and weeds in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Morrison, L.G. (1953) Apple leaf-curling midge in New Zealand. *New Zealand journal of agriculture* 86, 311-315.

Muggeridge, J. (1929) Biological control of pear midge (*Perrisia pyri*) in New Zealand. The present situation. *New Zealand journal of agriculture* 38, 317-320.

Myers, J.G. (1927) Natural enemies of the pear leaf-curling midge, *Perrisia pyri*, Bouché (Dipt., Cecidom.). *Bulletin of entomological research* 18, 129-138.

Penman, D.R. (1984) Deciduous tree fruit pests. Pp. 33-50 in Scott R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.

Sweetman, H.L. (1935) Successful examples of biological control of pest insects and plants. *Bulletin of entomological research* 26, 373-377.

Todd, D.H. (1956) A preliminary account of *Dasyneura mali* Kieffer (Cecidomyiidae: Dipt.), and an associated hymenopterous parasite in New Zealand. *New Zealand journal of science and technology* 37, 462-464.

Todd, D.H. (1959) The apple leaf-curling midge, *Dasyneura mali* Kieffer, seasonal history, varietal susceptibility and parasitism 1955-1958. *New Zealand journal of agricultural research* 2, 859-869.

Vlug, H.J; De V. Graham, M.W.R. (1984) The types of Platygasteridae (Hymenoptera, Scelionoidea) described by Haliday and Walker and preserved in the National Museum of Ireland and the British Museum (Natural History). 2. Keys to species, redescriptions, synonomy. *Tijdschrift voor Entomologie* 127, 115-135.

Diaspididae, armoured scales (Homoptera)

M.G. HILL

Pest Status

There are eight economically important diaspid scale insects in New Zealand, plus two others which are pests in home gardens (Table 31.1).

Quadraspidiotus perniciosus (Comstock) (San José scale) is a serious pest of pip and summerfruit in the North Island and the northern part of the South Island, and has been found in small numbers in Central Otago (Emms & McLaren 1984). It is also present on shelter trees, notably poplar and willow (Shaw 1986). It can cause death of all or part of heavily infested trees, and is a major quarantine pest on apples with a nil tolerance on exported fruit.

Quadraspidiotus ostreaeformis (Curtis) (oystershell scale) replaces San José scale as the dominant pip and summerfruit scale in central and southern South Island (Emms & McLaren 1984, Richards 1960, Wilson 1964). It is also present on several shelter species (McLaren 1983). It is less damaging than San José scale but faces the same export quarantine restrictions.

Lepidosaphes ulmi (L.) (apple mussel scale) is a sporadic pest of pip-fruit and shelter, and may occasionally be present in numbers sufficient to debilitate the plant (Penman 1984, Thomas 1981).

Hemiberlesia rapax (Comstock) (greedy scale) is a major quarantine pest on kiwifruit with a nil-tolerance on export kiwifruit, but is not known to seriously damage or kill plants. It is also found on shelter species and occasionally on apples (Ferguson 1979).

Hemiberlesia lataniae (Signoret) (latania scale) has been recorded as a quarantine interception on imported plants since at least 1951 and has been regularly recorded on ornamentals in greenhouses and nurseries. In 1977, it was first recorded away from a nursery on *Hypericum* sp. in a garden in Papatoetoe, and it was first recorded on kiwifruit in 1987 at Gisborne (Morales 1988). It has subsequently been reported on kiwifruit from several orchards in the North Island. Its range and pest status are under investigation but are ill defined at the time of writing.

Aspidiotus nerii Bouché (oleander scale) is present on kiwifruit, and is secondary to greedy scale as a pest. It appears to be concentrated on kiwifruit bark and usually makes up less than 5% of scale records on kiwifruit fruit at harvest (J. Berry & Hill unpublished).

Aonidiella aurantii (Maskell) (California red scale) occurs mainly in the north of the North Island, where it is a major quarantine pest on export citrus. If allowed to build up to high numbers on citrus trees, it can cause dieback and leaf fall (Penman 1984).

Parlatoria pittospori Maskell (mauve pittosporum scale) used to be a serious pest of orchards in the north of the South Island, but its pest status has been greatly reduced in recent years due to cultural practices and oil sprays aimed at controlling infestations on shelter belts of *Pinus radiata* D. Don (Pinaceae) (Penman 1984, Timlin 1964).

Pseudaulacaspis (= *Phenacaspis*) *eugeniae* (Maskell) (waratah scale) is a conspicuous and potentially very damaging pest of waratah, an introduced ornamental protea species. Large populations are capable of killing trees (Somerfield 1984).

Aulacaspis rosae (Bouché) (rose scale) can seriously damage and occasionally kill roses if untreated (Somerfield 1984).

In the North and South Islands San José scale has two to three generations per year on apples (Collyer & van Geldermalsen 1975, G. McLaren pers. comm., Wearing 1976). Greedy

Table 31.1 List of pest diaspid scales in New Zealand, their main hosts and distribution. NI = North Island, SI = South Island

Scales	Main hosts	Distribution
Quadraspidiotus perniciosus San José scale	Deciduous tree crops especially pipfruit and shelter	Nelson & Marlborough regions of SI
Quadraspidiotus ostreaeformis oystershell scale	Pip and summerfruit and shelter	Central and southern parts of SI
Lepidosaphes ulmi apple mussel scale	Occasional pest of pip, summer & berry fruit & shelter species	Throughout NZ
Hemiberlesia rapax greedy scale	Kiwifruit and shelter	NI and northern SI
Hemiberlesia lataniae latania scale	Kiwifruit,shelter and ornamentals	NI, distribution not known precisely, probably spreading.
Aspidiotus nerii oleander scale	Kiwifruit and shelter	NI and northern SI
Aonidiella aurantii California red scale	Citrus crops	Throughout NZ
Parlatoria pittospori mauve pittosporum scale	Deciduous tree crops & shelter, especially *Pinus radiata*	Northern SI
Pseudaulacaspis eugeniae waratah scale	Waratah trees (*Telopia* sp. (Proteaceae)) and other ornamentals	Northern NI
Aulacaspis rosae rose scale	Rose bushes	Throughout NZ

scale and oleander scale also have two to three generations on kiwifruit in the North Island (Ferguson 1979). Oystershell scale has one generation on apples in southern South Island (Richards 1962), and mussel scale has one generation in the South Island and a partial second generation in warmer North Island localities (Thomas 1981).

Background

With one exception, the existing natural enemies of these scale insects are indigenous.

Pathogens

The entomophagous fungus *Gibberella baccata* (= *Fusarium lateritium*) has been recorded from all stages of greedy scale (Ferguson 1974). Collyer & van Geldermalsen (1975) reported that fungi killed up to 50% of San José scales in Nelson.

Predators

The coccinellid beetle *Orcus chalybeus* (Boisduval) was introduced from Australia in 1899 and 1905 for control of black scale (*Saissetia oleae* (Olivier)) and blue gum scale (*Eriococcus coriaceus* Maskell) (see Chapters 40, 45) but has been recorded feeding on citrus red scale and San José scale (Valentine 1967). An endemic coccinellid *Scymnus fagus* Broun has been recorded feeding on oleander scale (Hill unpublished). The predatory mite *Neophyllobius* sp. (Stigmaeidae) has been reported in oystershell scale infestations (Richards 1960, 1962).

The information on predators attacking diaspid scales is scanty and anecdotal. However, recent laboratory observations suggest that *Scymnus fagus* may be a significant predator of the relatively soft-scaled oleander scale, though not of the harder-scaled greedy scale (Hill unpublished). This agrees with suggestions elsewhere (Rosen & DeBach 1978) that the success of predatory coccinellids in controlling diaspid scales is confined to those species with a 'relatively thin and readily penetrated covering' (Clausen 1940). There appears to be no information on the extent of predation in any of the other scale insect species in New Zealand.

Parasitoids

A complete list of parasitoids and the families to which they belong is given in Table 31.2. Reported rates of parasitism in San José scale are variable. Collyer & van Geldermalsen (1975) recorded *Aphytis mytilaspidis* Le Baron (= *A. albidus* Westwood), a solitary ectoparasitoid, as abundant in 1966-67 on apples in Nelson and *Encarsia citrina* (Craw), a solitary endoparasitoid, was also present. Between 1968 and 1970, percentage parasitism ranged from 20-88% at this location, and the dominant parasitoid species was *E. citrina*. However, a uniparental strain of *Encarsia perniciosi* (Tower) parasitised an increasing proportion of scales between 1968 and 1970. Parasitism by this species decreased over the summer as reported in California (Rice & Jones 1982). Between 1968 and 1970, *A. mytilaspidis* and *A. diaspidis* (Howard) occurred in Nelson in small numbers and increased late in the season. Collyer & van Geldermalsen (1975) reported higher parasitism of scales living on young apple branches than of scales on the bark of older parts of the trees. From 1978 to the early 1980s in Nelson, the most common parasitoid caught in San José scale pheromone traps was *E. perniciosi* although *E. citrina*, *A. diaspidis*, and *A. mytilaspidis* were also recorded (C.H. Wearing pers. comm.). Parasitism does not keep San José scale populations down to acceptable commercial levels, and sprays are necessary to prevent fruit infestation.

Parasitism of oystershell scale is also variable (Richards 1962), but can rise to levels of 80-100% from October to December. *Encarsia citrina* was again the dominant parasitoid, and Richards (1962) mentions that the predatory mite *Neophyllobius* sp. was very common in high infestations of oystershell scale. More recently, G. McLaren (pers. comm.) records *Encarsia citrina* and *Aphytis mytilaspidis* from oystershell scale in Central Otago, the latter being more abundant. These natural enemies do not prevent scales infesting fruit, and insecticide spraying of export crops in Central Otago is essential (G. McLaren pers. comm.).

No quantitative data are available for mauve pittosporum scale parasitism, but Timlin (1964) states that samples from low down on *Pinus radiata* trees were often heavily parasitised, and parasitism declined with increasing height on the tree. The two species involved were *E. citrina* and *A. chilensis*.

Rates of parasitism of adult greedy scale in unsprayed orchards are often over 50% and can be as high as 80-90%, with dominance alternating between *Signiphora merceti* (Malenotti) and *E. citrina* (D. Steven, M.G. Hill & D.J. Allan unpublished data). *Signiphora flavella* Girault is also commonly found but is rarely dominant. *S. merceti* and *S. flavella* have the drawback that they do not kill their host until after the host has begun to reproduce. Work on parasitism of kiwifruit armoured scale insects is continuing. Careful spraying is essential for the prevention of scale infestations on export kiwifruit.

Table 31.2 Parasitoids of economically important diaspid scales in New Zealand. (after Noyes (1988), Valentine & Walker (1989) and Hill unpublished)

Q.p	= *Quadraspidiotus perniciosus*	Q.o	= *Q. ostreaeformis*
L.u	= *Lepidosaphes ulmi*	P.p	= *Parlatoria pittospori*
A.a	= *Aonidiella aurantii*	H.r	= *Hemiberlesia rapax*
H.l	= *Hemiberlesia lataniae*	A.n	= *Aspidiotus nerii*
P.e	= *Pseudaulacaspis eugeniae*	A.r	= *Aulacaspis rosae*

Parasitoid	Host species									
	Q.p	Q.o	L.u	P.p	A.a	H.r	H.l	A.n	P.e	A.r
HYMENOPTERA: APHELINIDAE										
Aphytis diaspidis (Howard)	*									
Aphytis mytilaspidis Le Baron	*	*	*							
Aphytis chilensis Howard				*	*	*		*		
Aphytis chrysomphali (Mercet)					*					
Encarsia citrina (Craw)	*	*	*	*	*	*	*	*	*	*
Encarsia perniciosi (Tower)	*				*					
ENCYRTIDAE										
Adelencyrtus aulacaspidis (Brèthes)										*
Arrhenophagus chionaspidis Aurivillius										*
Zelaphycus aspidioti (Tachikawa & Valentine)								*		
Epitetracnemus zetterstedtii (Westwood)			*							
Zaomma lambinus (Walker)			*							
SIGNIPHORIDAE										
Signiphora merceti (Malenotti)					*	*	*			
Signiphora flavella Girault					*	*				

Importations, Releases and Recoveries

Compared with the extensive efforts made in many overseas countries to import biological control agents for Diaspididae (Rosen & DeBach 1978), relatively little has been attempted in New Zealand.

Predators

In 1899 and 1905, *Orcus chalybeus* was introduced from Australia, and has been recorded feeding on San José scale and red scale, as well as black scale and blue gum scale (see Chapters 40, 45).

In 1967, the predaceous mite *Hemisarcoptes malus* (Shimer) was imported to Nelson from Nova Scotia on apple twigs infested with mussel scale. It was released directly into the field, onto apple trees infested with San José scale, plum trees infested with mussel scale, and oleander and evergreen laurel infested with black scale. The mite established at several sites on both oystershell scale and black scale, and persisted for several years (E. Ashley pers. comm. DSIR files, P. Insley unpublished report DSIR files). The mite never became abundant, and there is no evidence of its having spread from its release sites, most of which have now been destroyed (E. Ashley pers. comm.). Its present status is therefore uncertain. More information on release sites can be obtained from Insley's report (unpublished DSIR files).

Parasitoids

In 1923, an unsuccessful attempt was made to introduce and establish *Encarsia citrina* from the U.S.A. to control San José scale, although this parasitoid was already present in New Zealand (DSIR files, Dumbleton 1936).

In 1947, *Comperiella bifasciata* Howard was imported from Australia but did not establish (DSIR files).

In 1959/60, a total of 14 shipments of scale parasitoids was sent from India to New Zealand for San José scale control (Rao & Rao 1961). Eight of these were of *Encarsia perniciosi* (Tower) 'California strain', one was of *E. perniciosi* 'Russian strain' and five were of *Aphytis diaspidis*. Early reports suggested that both of these parasitoids had become established (DSIR files, Rao & Rao 1961). However, both were present in New Zealand before this introduction (Valentine 1963 and pers. comm.), and it is impossible to ascertain whether the imported strains have persisted or have had a significant impact upon diaspid scale populations.

Conclusions

Compared with well known and highly successful biological control efforts overseas, biological control of diaspid scales in New Zealand has received very little attention. Unfortunately, the most important pest species – San José, oystershell, oleander and greedy scale – also provide the most difficult problems because there is a nil tolerance for these pests on all exported fruit. For this reason, biological control of these species is unlikely to be completely successful unless export tolerances are changed. However, there remains enormous scope for the importation of natural enemies of Diaspididae from many parts of the world, which may reduce the use of pesticides by reducing diaspid scale populations on alternative host plants.

At the time of writing, there are well advanced plans to import predatory *Hemisarcoptes* mite species from Israel and North America, along with their associated phoretic agents, ladybeetles in the genus *Chilocorus*. These will be targeted mainly at scales on kiwifruit but are expected to attack other pest diaspid scales (M.G.Hill, D.J.Allan ongoing research).

Acknowledgements

Gillian McLaren, Howard Wearing, Peter Shaw and Warren Thomas provided valuable comments and unpublished observations.

Literature Cited

Clausen, C.P. (1940) Entomophagous insects. McGraw-Hill, New York, U.S.A. 688 pp.

Collyer, E.; van Geldermalsen, M. (1975) Integrated control of apple pests in New Zealand. 1. Outline of experiments and general results. *New Zealand journal of zoology* 2, 101-134.

DSIR, Entomology Division, file BC 1/4.
Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.
Emms, L.E.; McLaren, G.F. (1984) San José scale *Quadraspidiotus perniciosus* (Comstock) (Homoptera: Diaspididae) in Central Otago. *New Zealand entomologist* 8, 81-82.
Ferguson, A.M. (1974) Biology of greedy scale, *Hemiberlesia rapax* (Com.) on kiwifruit. Pp. 20-26 in *Proceedings of kiwifruit seminar held at Tauranga*. New Zealand Ministry of Agriculture and Fisheries publication.
Ferguson, A.M. (1979) Greedy scale *Hemiberlesia rapax* (Comstock), life cycle. *DSIR information series* 105/31, 2 pp.
McLaren, G.F. (1983) Oystershell scale control. Pp. 24-28 in *Winter Seminar Proceedings 1983*. New Zealand Ministry of Agriculture and Fisheries, Advisory Services Division, Alexandra.
Morales, C.F. (1988) The occurrence of latania scale, *Hemiberlesia lataniae* (Signoret) (Hemiptera: Diaspididae) in New Zealand. *New Zealand journal of experimental agriculture* 16, 77-82.
Noyes, J.S. (1988) Encyrtidae (Insecta: Hymenoptera) *Fauna of New Zealand* 13, 188 pp.
Penman, D.R. (1984) Subtropical fruit pests. Pp. 51-64 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.
Rao, V.P.; Rao, V.S. (1961) Natural enemies of San José scale, red scale and *Antonina indica*. P. 16 in Report of work carried out during 1960. Unpublished report, CIBC. 41 pp.
Rice, R.E.; Jones, R.A. (1982) Collections of *Prospaltella perniciosi* Tower (Hymenoptera: Aphelinidae) on San José scale (Homoptera: Diaspididae) pheromone traps. *Environmental entomology,* 11, 876-880.
Richards, A.M. (1960) Scale insect survey on apples 1959-1960. *New Zealand journal of agricultural research* 3, 693-698.
Richards, A.M. (1962) The oystershell scale, *Quadraspidiotus ostreaeformis* (Curtis), in the Christchurch district of New Zealand. *New Zealand journal of agricultural research* 5, 95-100.
Rosen, D.; DeBach, P. (1978) Diaspididae. Pp. 78-128 in Clausen, C.P. (ed.) Introduced parasites and predators of arthropod pests and weeds: A world review. *United States Department of Agriculture, agriculture handbook* 480.
Shaw, P.W. (1986) The susceptibility of selected shelter trees to San José scale *Quadraspidiotus perniciosus* (Comstock). *The Orchardist of New Zealand* November 1986, 416-417.
Somerfield, K.G.. (1984) Greenhouse and ornamental pests. Pp. 65-92 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.
Thomas, W.P. (1981) Apple mussel scale *Lepidosaphes ulmi* (L.) life cycle. *DSIR information series* 105/39, 2 pp.
Timlin, J.S. (1964) The biology and control of *Parlatoria pittospori* Mask. (Hemiptera: Diaspididae): a pest on apples in New Zealand. *New Zealand journal of agricultural research* 7, 536-550.
Valentine, E.W. (1963) New records of hymenopterous parasites of Homoptera in New Zealand. *New Zealand journal of science* 6, 6-13.
Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.
Valentine, E.W.; Walker, A.K (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, in press.
Wearing, C.H. (1976) San José scale *Quadraspidiotus perniciosus* (Comstock), life cycle. *DSIR information series* 105/21, 2 pp.
Wilson, D.W. (1964) Scale insects. Unpublished internal report, Advisory Services Division, New Zealand Ministry of Agriculture and Fisheries, Roxburgh. 3 pp.

Edwardsiana crataegi (Douglas) (= *Typhlocyba froggatti* Baker), Froggatt's apple leafhopper (Homoptera: Cicadellidae)

J.G. CHARLES

Pest Status

Edwardsiana crataegi (Douglas) was described from south-eastern England (as *Typhlocyba crataegi*) on both hawthorn and apple (Douglas 1876). Froggatt (1918) described *Empoasca australis* from New South Wales, and it was recorded on apple trees in New Zealand at about the same time (Cockayne 1919). Baker (1925) gave the name *Typhlocyba froggatti* to *T. australis* Myers (1923) (= *Empoasca australis*), and this name has been retained in common use in New Zealand since then. However, Günthart (1971) showed that the most distinctive morphological difference between *E. crataegi* and *T. froggatti* (the shape of the lobes of the aedeagus) was due to intraspecific variation. Both forms of aedeagus have been found in specimens labelled *T. froggatti* in the New Zealand Arthropod Collection (C.F. Morales pers. comm.). Nast (1972) synonymised *E. crataegi* with *T. froggatti* and the current European literature assumes the two species to be identical (M.R. Wilson pers. comm.). I consider that the correct name for Froggatt's apple leafhopper in New Zealand is *E. crataegi*.

E. crataegi occurs throughout Europe and North America, and in Argentina and Chile. Records suggest that the species was introduced into Australasia from the Northern Hemisphere, probably as eggs in imported trees, rootstocks or cuttings (Dumbleton 1934). *E. crataegi* is now widely distributed in New Zealand, and is recorded from Auckland to Dunedin (Dumbleton 1934, Knight 1976).

Following the discovery of *E. crataegi* in New Zealand, it was initially considered to be a significant apple pest (Cockayne 1919, Miller 1922). Some control was achieved by nicotine (Dumbleton 1934) but with the advent of DDT, *E. crataegi* was reduced to a minor component of the pest complex of apples, where it has remained following the change to organophosphate insecticides (OPs). Collyer & van Geldermalsen (1975) recorded that the plant-derived compound ryania gave good control of *E. crataegi*. In spite of the intensive use of OPs in apple orchards in New Zealand over the past 20-25 years, no confirmed cases of OP resistance have been recorded. However, failure of OPs to control *E. crataegi* has been reported in about 12 apple blocks in Hawke's Bay during 1986 and 1987 (J.T.S. Walker pers. comm.). In the U.S.A., the closely related *T. pomaria* McAtee (Cicadellidae) developed resistance to azinphos-methyl in the late 1960s, resulting in serious outbreaks of the pest (Trammel 1974). Should *E. crataegi* resistance to azinphos-methyl occur in New Zealand, it could rapidly change from being a minor pest to become a major problem because of the emphasis in New Zealand on the production of blemish free fruit for export markets.

Background

E. crataegi is predominantly a pest of apple. It has also been found on hawthorn and raspberry in New Zealand (Knight 1976) but most studies suggest that development can be completed only on apple and probably hawthorn (Claridge & Wilson 1976). *E. crataegi* is in the subfamily Typhlocybinae, the species of which all feed on mesophyll in the pallisade and spongy parenchyma of leaves - in contrast to other subfamilies of the Cicadellidae which feed in the vascular tissues (Chiswell 1964). Feeding damage is characterised by spotting on the

upper surface of leaves. Large numbers of leafhoppers can cause defoliation, reduction in plant vigour and consequent crop loss. Excreta from all stages may also contaminate the surface of fruit, providing a substrate for sooty mould fungi which reduce the value of the crop. The biology of *E. crataegi* in New Zealand was first studied by Dumbleton (1934). Teulon (1983) extensively reviewed the existing literature for *E. crataegi* and studied aspects of the biology and management of the leafhopper as they relate to modern integrated pest management (IPM) practices in New Zealand. In Canterbury and Nelson, *E. crataegi* develops through two and possibly a partial third generation each year. They overwinter as eggs which are laid into the bark on the lower side of twigs from mid-February until early April. Eggs begin to hatch in late September and the first adults appear in early November. Eggs of the second generation are laid in midribs and veins of leaves from early December and hatch in early January. Adults of this generation mature in late January and have all died by mid-April (Dumbleton 1934, Teulon 1983).

Three species of natural enemy have been associated with *E. crataegi* in the New Zealand literature. In 1932, overwintering eggs were found to be parasitised by *Anagrus armatus* (Ashmead) (Hymenoptera: Mymaridae), a species known also to parasitise *E. crataegi* and *T. pomaria* in the U.S.A. (Clausen 1978, Dumbleton 1934). At that time Dumbleton considered it likely that *A. armatus* would prove to be of European origin but current knowledge does not support this notion and it seems likely that *A. armatus* was brought to New Zealand from the U.S.A. Dumbleton (1934) described the biology of *A. armatus*, which had two (or a partial third) generations a year. Between 78 and 93% of overwintering eggs were parasitised in Nelson, and about 80% of eggs collected from each of Auckland, Hastings, Blenheim and Dunedin were also parasitised. Sixty six percent of summer eggs were parasitised. Teulon (1983) estimated parasitism by *A. armatus* of overwintering eggs in an unsprayed orchard in Canterbury to be 32-53% (but considered that this estimate may have been low) and from 20-100% of summer eggs. The wide range of percentage parasitism depended on collection dates, because at the end of summer unparasitised eggs had hatched so that all remaining eggs were parasitised. Dumbleton (1937) found that some *A. armatus* emerged from overwintering host eggs in the autumn and considered that these individuals also contributed to a high level of parasitism of winter eggs. Dumbleton (1937) considered that leafhopper outbreaks may be caused by weather conditions unfavourable to *A. armatus* survival. Cottier (1956) considered that *A. armatus* was incapable of preventing *E. crataegi* damage. This opinion was supported by Collyer & Geldermalsen (1975). However, *A. armatus* from New Zealand was introduced into Tasmania in 1935 and established so well in the main apple areas that 'by 1947 *E. crataegi* had not been a serious problem in such areas for several years' (Wilson 1960 p. 20). *Anagrus* sp. is also frequently recorded from eggs of *Ribautiana tenerrima* (Herrich-Schäffer) (Hemiptera: Cicadellidae) on *Rubus* spp. in Auckland and Central Otago (Charles unpublished).

Dumbleton (1938) proposed that *Sejanus* (= *Idiatella*) *albisignata* (Knight) (Hemiptera: Miridae) might be predatory on the eggs of *E. crataegi*, but did not attempt to confirm it.

Teulon (1983) recorded predation of adult *E. crataegi* by a spider, *Episinus* sp. (Theridiidae). Although the attacks were recorded only in the laboratory, the spiders left exoskeletal remains similar to those found in the field.

In other countries, Dryinidae (Hymenoptera) and Pipunculidae (Diptera) are important natural enemies of Cicadellidae. We have little knowledge of the New Zealand fauna in either of these two families. Native dryinids are known from leafhoppers (Homoptera: Jassidae) near Lake Rotoiti (Nelson) (Gourlay 1954), and from *Nilaparvata myersi* Muir (Homoptera: Delphacidae) in Auckland (A.K. Walker pers. comm.). Myers (1923) recorded that Typhlocybinae leafhoppers parasitised by dryinids 'were not very numerous'. Pipunculid adults are sometimes numerous in malaise trap catches from native bush (Charles unpublished), but there have been no introductions of exotic pipunculids into New Zealand. I have been unable to find any records of pipunculid parasitism of any of the Typhlocybinae in New Zealand.

Dumbleton (1934) reviewed the existing literature on natural control agents of leafhoppers in Europe and the U.S.A. and concluded that as an egg parasitoid was already present in New Zealand, efforts should be made to identify and obtain dryinid nymphal parasitoids of *E. crataegi* for release into New Zealand.

Importations, Releases and Recoveries

Dumbleton (1937) reported that a search for specific parasitoids of *E. crataegi* from the Imperial Institute of Entomology in England (DSIR files) had been unsuccessful, but that an offer of *Aphelopus typhlocybae* Muesebeck (Hymenoptera: Dryinidae) from New York had been accepted. *A. typhlocybae* was regarded as an important parasitoid of *T. pomaria*, and there were no indications that it was rigidly host specific. A consignment of 1,250 cocoons of *A. typhlocybae* (collected by H.M. Steiner of the New York Agricultural Experiment Station 12-14 October 1935) arrived at Nelson on 12 November 1935. A total of 371 adults subsequently emerged, and 239 of these were liberated; 70 onto an unsprayed leafhopper infested hedge around the laboratory of the Cawthron Institute (late January to early March 1936), and 169 into a heavily infested but rarely sprayed orchard located between the Appleby Research Orchard and Mapua (late February 1936). The remaining adults were retained for experiments in the laboratory during which it was confirmed that *A. typhlocybae* would parasitise *E. crataegi* and were capable of completing development in this host (Dumbleton 1937).

A second shipment of *A. typhlocybae* cocoons was sent from New York on 11 November 1936, arriving in New Zealand on 9 December (DSIR files). Of 800 cocoons shipped, only 25 emerged (early March), and 16 were released on to *E. crataegi* infested apple trees in the Cawthron Institute insectary. The remainder died shortly after emergence (DSIR files).

During a survey of the sites at which *A. typhlocybae* were released in 1935/36, carried out during February and March 1937, 2,490 *E. crataegi* nymphs were collected and dissected. No evidence of parasitism was found (Cawthron 1936, DSIR files).

From 1980-1982, Teulon (1983) trapped more than 100,000 *E. crataegi* on yellow sticky boards in Christchurch, and recorded that none was parasitised by dryinids.

Evaluation

E. crataegi is not currently an important pest in commercial apple orchards, because chemical insecticides applied for leafroller and mealybug control keep it at low levels. However, on unsprayed trees *Anagrus armatus* may be unable to prevent it from appearing in large numbers, damaging foliage and leading to disfiguring sooty mould on the fruit. The introduction of *Aphelopus typhlocybae* appears to have been unsuccessful and no recoveries have been made since its liberation in 1936.

Conclusions

E. crataegi is currently controlled well by spray programmes for other pests in commercial orchards. The impact of predatory insects, such as the introduced Miridae or spiders, on *E. crataegi* populations in the absence of pesticides is not known. If the pest status of *E. crataegi* increases, for example, because of developing resistance to organophosphate insecticides, or the increasing value of pesticide-free fruit, then the role of natural enemies should be evaluated. Priority should be given to locating and evaluating the predatory mirids, and parasitoids of the families Mymaridae, Dryinidae and Pipunculidae which occur in the Palaearctic Region (particularly in the U.K.), with a view to their introduction. The nymphal

parasitoids can reduce equilibrium levels of their host leafhoppers (M.A. Jervis pers. comm.), and the Mymaridae may also play an important role in population regulation.

Literature Cited

Baker, C.F. (1925) Nomenclatorial notes on the Jassoidea, IV. *Philippine journal of science* 27, 537.

Cawthron Institute (1960) Annual report, 12.

Chiswell, J.R. (1964) Observations on the life-histories of some leafhoppers (Homoptera: Cicadellidae) occurring on apple trees, and their control with insecticides. *Journal of horticultural science* 39, 9-23.

Claridge, M.F.; Wilson, M.R. (1976) Diversity and distribution patterns of some mesophyll-feeding leafhoppers of temperate woodland canopy. *Ecological entomology* 1, 231-250.

Clausen, C.P. (1978) Cicadellidae. pp. 55-57 in Clausen, C.P. (ed.), Introduced parasites and predators of arthropod pests and weeds. A world review. *United States Department of Agriculture, Agriculture handbook* 480.

Cockayne, A.H. (1919) Annual report *Report of the New Zealand Department of Agriculture* 1918-19, 42.

Collyer, E.; van Geldermalsen, M. (1975) Integrated control of apple pests in New Zealand 1. Outline of experiment and general results. *New Zealand journal of zoology* 2, 101-134.

Cottier, W. (1956) Insect pests. Pp. 211-441 in Plant protection in New Zealand. Government Printer, Wellington, New Zealand, 699 pp.

Douglas, J.W. (1876) British Hemiptera-Homoptera - additional species. *Entomologists monthly magazine* 12, 203-204.

DSIR files, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1934) The apple-leafhopper (*Typhlocyba australis* Frogg.). *New Zealand journal of science and technology* 16, 30-38.

Dumbleton, L.J. (1937) Apple leafhopper investigations. *New Zealand journal of science and technology* 18, 866-877.

Dumbleton, L.J. (1938) Notes on a new mirid bug (*Idiatella albisignata* Knight). *New Zealand journal of science and technology* 20, 58-60.

Froggatt, W.W. (1918) The apple-leaf jassid (*Empoasca australis*). *New South Wales agricultural gazette* 29, 568-571.

Gourlay, E.S. (1954) The Dryinidae, a family of Hymenoptera new to New Zealand. *New Zealand entomologist* 1, 3-5.

Günthart, H. (1971) Kleinzikaden (Typhlocybinae) an Obstbaumen in der Schweiz. *Obst-Weinbau* 9, 285-306.

Knight, W.J. (1976) Typhlocybinae of New Zealand (Homoptera: Cicadellidae). *New Zealand journal of zoology* 3, 71-87.

Miller, D. (1922) Insect notes: 1921-22 season. *New Zealand journal of agriculture* 24, 294-296.

Myers, J.G. (1923) A contribution to the study of New Zealand leaf-hoppers and plant-hoppers (Cicadellidae and Fulgoridea). *Transactions and proceedings of the New Zealand Institute* 54, 407-429.

Nast, J. (1972) Palaearctic Auchenorrhyncha (Homoptera). An annotated check list. Polish Academy of Sciences, Institute of Zoology, Warsaw, Poland. 550 pp.

Teulon, D.A.J. (1983) Aspects of the biology and management of Froggatt's apple leafhopper (*Typhlocyba froggatti* Baker) in New Zealand. M.Hort.Sc. thesis, Lincoln College, University of Canterbury, New Zealand.

Trammel, K. (1974) The white apple leafhopper in New York – insecticide resistance and current control status. *Search agriculture* 4(8), 1-10.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Epiphyas postvittana (Walker), lightbrown apple moth (Lepidoptera: Tortricidae)

W.P. THOMAS

Pest Status

The lightbrown apple moth, *Epiphyas postvittana* (Walker), also known as apple leafroller or Australian leafroller, is of Australian origin but is now present as an introduced species in New Zealand, Britain, New Caledonia and Hawaii (Thomas 1965a). It was first reported in New Zealand in 1891 (Hudson 1928), but a female specimen deposited in the Canterbury Museum and dated 1887 was intercepted on fruit imported from Tasmania to Lyttleton. Its spread to countries outside Australia is largely a result of human activity (Meyrick 1937).

Lightbrown apple moth is polyphagous and is a particularly serious pest of horticultural fruit crops, pomefruit and berryfruit (Thomas 1965a) and can be a problem in young exotic forest plantings (Zondag 1985). *E. postvittana* and its commonly associated pest tortricid species '*Planotortrix excessana*' Walker and '*Ctenopseustis obliquana*' Walker are the key lepidopterous pests of many fruit crops (Wearing *et al.* in press). The taxonomic status of the commonly associated endemic species is currently under review (J.S. Dugdale pers. comm.). Geier & Briese (1981) list 123 host plants in Australia but 265 are known from New Zealand (Thomas unpublished). Unusually, apple is not reported as a host in Britain.

Mated females of the lightbrown apple moth deposit their eggs in imbricated series in batches, mainly on the dorsal (adaxial) leaf surface of plants during the first few nights of adult life. The neonate larvae spin protective silken niches on the abaxial surface of leaves, but in later instars may web leaves together or attach them to fruit. Fruit damage is mainly superficial, except for occasional direct fruit-tunnelling. In contrast to codling moth (Chapter 29) fruit feeding is largely incidental to the normal feeding behaviour of *E. postvittana* (Collyer & van Geldermalsen 1975). Larval development rate, and that of the endoparasitoids is dependent on temperature, and type and quality of the food plant (Danthanarayana 1975a, Dumbleton 1939). Prior to pupation, a loose silken cocoon is formed within the larval feeding site or often several centimetres away, within a newly rolled leaf. Three generations are completed annually in central New Zealand (Dumbleton 1932, Thomas 1965a) but there may be more in the North Island during favourable conditions.

Leafrollers, including *E. postvittana* are controlled in commercial fruit crops in New Zealand by the regular use of insecticides. In the past, lead arsenate was replaced by the organochlorine insecticides DDD and TDE, but widespread resistance to these compounds was reported in *E. postvittana* in Nelson in 1961-62 (Collyer & van Geldermalsen 1975). Organophosphorus insecticides, mainly azinphos-methyl, have been in general use since then.

Localised azinphos-methyl resistance was confirmed in populations of the lightbrown apple moth at Mariri, near Nelson, by Suckling *et al.* (1984) and this has led to various control measures being researched and adopted to confine the resistant population (Suckling *et al.* 1986, 1987). Isolation of the pheromone of *E. postvittana* (Bellas *et al.* 1983) has since enabled progress on the development of mating disruption for partial control of this pest (D.M. Suckling pers. comm.). Any reduction in the number of insecticide applications could improve the impact of leafroller parasitoids in orchards.

Background

Dumbleton (1932) provided the first comprehensive account of the biology of the lightbrown apple moth in apple orchards in Nelson, New Zealand, together with brief notes on parasitoids

reared. Further aspects of the ecology of this species in New Zealand are provided by Dumbleton (1939), C.J. Green (1984), Thomas (1965a) and Tomkins (1984). An account of the biology of the species and its parasitoids in Tasmania is given by Evans (1937), and various ecological and biological considerations have been followed in Australia by Danthanarayana (1975a, 1975b, 1983) and Geier & Briese (1980, 1981).

Natural enemies in New Zealand

Lightbrown apple moth is attacked by a wide range of parasitoids, predators, parasites and pathogens in New Zealand (Dumbleton 1932, Early 1984, Thomas 1965a, 1965b, Wearing *et al.* in press) and in Australia (Dumbleton 1940, Geier & Briese 1981, MacLellan 1973).

The known parasitoids in New Zealand are listed in Table 33.1. Trichogrammatid species, including *Trichogramma* (*Trichogrammanza*) *funiculatum* Carver and *Trichogrammatoidea bactrae fumata* Nagaraja, parasitise the eggs of the lightbrown apple moth and other tortricids. Levels of parasitism recorded for these species vary greatly. On citrus foliage at Appleby Research Orchard (Nelson), parasitism of egg batches was around 90% in autumn of 1969-70,

Table 33.1 Parasitoids reared from eggs, larvae and pupae of *E. postvittana* in New Zealand prior to importations in 1967 (modified from Thomas (1965a and unpublished))

Family	Species	Remarks
EGGS		
Hymenoptera: Trichogrammatidae	*Trichogramma* spp.	Solitary endoparasitic of egg but sometimes more than one per host
	Trichogramma (*Trichogrammanza*) *funiculatum* Carver	
	Trichogrammatoidea bactrae fumata Nagaraja	
LARVAE		
Diptera: Tachinidae	*Pales funesta* Hutton	Normally solitary endoparasitic often emerging from pupa
	Unidentified sp., ?*Pales feredayi* (Hutton)	
Hymenoptera: Braconidae	*Apanteles tasmanicus* Cameron	Solitary endoparasitic
	Apanteles demeter Wilkinson	Gregarious endoparasitic
	Apanteles sicarius Marshall	Solitary endoparasitic
	Apanteles sp. ?*ruficrus* (Haliday)	Gregarious endoparasitic
	Unidentified sp.	Solitary endoparasitic
Bethylidae	*Goniozus* sp.	Gregarious ectoparasitic
	Unidentified sp.	Gregarious ectoparasitic
Eulophidae	*Sympiesis* spp. (2)	Gregarious ectoparasitic
	Elachertus (= *Zelarchertus*) sp.	Gregarious ectoparasitic
Ichneumonidae	Unidentified sp. 1	Solitary endoparasitic
	Unidentified sp. 2	Solitary endoparasitic
	Unidentified sp. 3	Solitary endoparasitic
PUPAE		
Hymenoptera: Ichneumonidae	*Echthromorpha intricatoria* (F.)	Rare in this host, solitary, endoparasitic
	Lissopimpla excelsa (Costa)	Rare in this host, solitary, endoparasitic
	Aucklandella sp.	Uncommon, endoparasitic
Pteromalidae	*Trichomalopsis* sp.	Uncommon, gregarious endoparasitic

but parasitism in spring was often less than 10% (Thomas unpublished). Stevens (1988) found that trichogrammatid parasitism of leafroller egg masses in an unsprayed kiwifruit orchard at Kumeu never rose above 30% and rarely above 10%.

The braconid larval parasitoid *Apanteles tasmanicus* Cameron, of Australian origin, is consistently found in association with unsprayed, or infrequently sprayed, lightbrown apple moth populations in New Zealand and frequently invades orchards once the insecticide spray programmes cease in autumn. Dumbleton (1935) found parasitism levels in Nelson ranged between 20% and 51% for this species and this appears consistent with percentage parasitism reported by other workers (C.J. Green 1984, Thomas 1965a). The life cycle of *A. tasmanicus* is described by Dumbleton (1935). Hyperparasitism of this species by *Gelis* spp. (Ichneumonidae), a pteromalid species and *Pediobius* sp. (Eulophidae) is common both in New Zealand (Thomas 1965a) and in Australia (DSIR files).

Other parasitoids listed in Table 33.1 are generally less numerous, but may be of sporadic or of local importance, especially in relation to the host's food plant. S.E. Wunderink (unpublished report 1987, DSIR files) recorded high levels of parasitism of hosts by *A. demeter* Wilkinson on tea plantings at Riwaka (Nelson area).

Predators feed mainly on the active stages of lightbrown apple moth in New Zealand. These include syrphids (Miller & Watt 1915) *Oechalia schellembergii* (Guérin-Méneville), *Cermatalus nasalis* (Westwood) (Pentatomidae) (Ramsay 1963), *Forficula auricularia* L. (Dermaptera) (Chapter 35). *Vespula* spp. (Vespidae) and birds (Collyer & van Geldermalsen 1975, Thomas 1965a) but their impact on host populations is little known. Major natural mortality of neonate larvae (around 90%) occurs between egg eclosion and larval settlement (Thomas 1965a) and this probably includes some predation.

Dumbleton (1932) reported the presence of nematodes in larvae of *E. postvittana*. Parasitic gregarines often occur in the gut (Thomas 1965a, 1965b) and sometimes the body cavity. Gregarine infestations tend to delay larval maturation but do not appear to cause the death of hosts.

A fungal pathogen *Entomophthora* sp. causes sporadic mortality among larval infestations when weather conditions are favourable. At Appleby larval populations were severely decimated when warm, wet conditions prevailed in late summer (Collyer & van Geldermalsen 1975).

In dense larval infestations on apple at Appleby (Nelson area), a naturally occurring nuclear polyhedrosis virus, similar to that described by MacCollom & Reed (1971), sometimes decimated local concentrations of larvae (Thomas unpublished). Extracts of this virus made up from macerated infected larvae and applied in dilute spray form to apple trees provided control of *E. postvittana* larvae (Collyer & van Geldermalsen 1975, DSIR files). It was found that re-infection of larvae was possible from soil samples for up to two years following virus spraying (DSIR files).

Australian parasitoid surveys and collections

L.J. Dumbleton visited Australia in 1937 (Dumbleton 1940) in order to survey and collect parasitoids of lightbrown apple moth. He reared 11 species from collections made mainly in Tasmania and brought them back to New Zealand for emergence. These were used for identification purposes and no releases resulted. In his conclusions Dumbleton (1940) made the recommendation that in particular *Voriella uniseta* Malloch (Tachinidae), *Xanthopimpla rhopaloceros* Krieger (Ichneumonidae) and *Brachymeria* (= *'Chalcis'*) sp. (Chalcididae) should be introduced from Australia.

This recommendation was first acted upon when I conducted surveys and collections in the eastern states of Australia and Tasmania in 1967 and 1969. Approximately 19 parasitoid species and three predator species (*Chrysopa* spp. (Chrysopidae)), were introduced. The parasitoids which emerged are listed in Table 33.2, and initial field evaluations are incorporated in unpublished reports (DSIR files). Collections were undertaken near Sydney (New

Table 33.2 The main parasitoids reared from larvae and pupae of *E. postvittana* in quarantine at Nelson from collections made in eastern Australia and Tasmania in 1967 (Jan.-Feb.) and 1969 (Jan.-Apr.) with numbers emerged and numbers directly released in a field cage at Appleby, A and in Nelson, N.

	Species	No. emerged		No. released directly	
		1967	1969	1967	1969
LARVA/PUPA					
Diptera: Tachinidae	*Voriella uniseta* Malloch	81	224	50 A	200 AN
	Trigonospila brevifacies Hardy	41	49	39 A	20 A
	Unidentified sp., ?spp.	13	233,9	0	0,0
LARVA					
Hymenoptera: Braconidae	*Apanteles tasmanicus* Cameron	*	295	-	244 N
	Meteorus sp. (from Tasmania only)	0	4	0	0
Bethylidae	*Goniozus* sp.	*	115	-	100 AN
Ichneumonidae	*Diadegma* sp.	2	340	0	250 N
	Australoglypta latrobei Gauld	0	44	0	20 N
	Temelucha sp.	0	207	0	0
	Agathiella sp. (from Tasmania only)	0	1	0	0
	Unidentified sp. (from Tasmania only)	0	3	0	0
PUPA					
Hymenoptera: Chalcididae	*Brachymeria phya* (Walker)	67	266	50 A	200 AN
	Brachymeria teuta (Walker)	241	52	200 AN	40 A
	Brachymeria sp.	0			0
Ichneumonidae	*Xanthopimpla rhopaloceros* Krieger	4	31	0	12 N
	Glabridorsum stokesii (Cameron)	8	34	0	11 N
	Exochus sp.	15	0	0	0

Hyperparasitoids that emerged were destroyed and remain unclassified
* = not collected

South Wales), near Canberra (Australian Capital Territory), Melbourne and the Mornington Peninsula (Victoria) , Hobart and the Huon Valley (Tasmania).

Most parasitised hosts (mainly *E. postvittana*) were collected on healthy, infrequently sprayed, young apple trees in a commercial orchard. Few hosts were found on abandoned apple trees in orchards under severe water stress. Differences were noted in the complex of parasitoids collected. In 1967, *Exochus* sp. (Ichneumonidae) was found in reasonable numbers, but was not found in 1969. A *Temelucha* sp. (Ichneumonidae), present in considerable numbers in 1969, emerged from the same age class of larvae as *A. tasmanicus*. Although present, *A. tasmanicus* was not collected in 1967. Also, *Australoglypta latrobei* Gauld (Ichneumonidae) (identified by E. Riek in 1969 as *Glypta* sp.) was collected in 1969 only, from hosts on strawberries at Noble Park, Victoria, none being taken on apple. A eumenid wasp was observed collecting larvae from leaf-rolls on apple trees in Hastings, Victoria in 1969, but none of these were collected. This is probably the species referred to by Evans (1937).

Importations, Releases and Recoveries

Importations from Australia, 1922
Goniozus sp. (Hymenoptera: Bethylidae)

In 1922 R.J. Tillyard forwarded to Nelson several pupal cocoons of *Goniozus* sp. ?*antipodum* Westwood from Australia. According to E.S. Gourlay (unpublished report DSIR files) attempts were made to mass-produce this species, but the adult parasitoids escaped. This constituted a release (Dumbleton 1936), but since the species was later found to be common in other districts it is assumed that it was already present in New Zealand at the time of the introduction.

Importations from Australia in 1967 and 1969

Of the species introduced during 1967 and 1969, *V. uniseta*, *Trigonospila brevifacies* (Hardy) (Tachinidae), *Brachymeria phya* (Walker), *B. teuta* (Walker) (= *B. rubripes* Girault) (Chalcididae) were directly released from quarantine into the field (Table 33.2) in 1967. The larval/pupal parasitoid *T. brevifacies* was cultured in part and released in 1967-1972 and the pupal parasitoids *B. phya*, *B. teuta*, *Brachymeria* sp., *X. rhopaloceros* and *Glabridorsum stokesii* (Cameron) (Ichneumonidae) were also cultured after importation and releases were made (Thomas 1975). This rearing programme was greatly enhanced by the formulation of a simple artificial diet (Thomas 1968) for mass-rearing pupae of lightbrown apple moth.

Tachinidae (Diptera)

Attempts to culture *V. uniseta* and the unidentified tachinid were unsuccessful. Direct releases of imported *V. uniseta* and *T. brevifacies* were made in April/May 1967 into tree cages at Appleby Research Orchard enclosing *E. postvittana* infestations. Adults of a new generation were observed in September 1967, but the two parasitoid species failed to become established in this locality from this or other releases made at Appleby.

T. brevifacies was released in Kerikeri (by R.A. Cumber, DSIR files), Hamilton, Tauranga, Nelson and Christchurch during the period 1967-1972. R.A. Cumber (DSIR files) first reported the establishment of this species in Kerikeri in 1972. Since then, the species has spread to many regions in the North Island and is known as far south as Levin. The species was also redistributed to Havelock North, Christchurch and Nelson in 1981-82 and Christchurch 1987 (J.R. Clearwater pers. comm.). O.R. Green (1984) noted several hosts; *Ctenopseustis obliquana* (Walker), '*Cnephasia*' *jactatana* (Walker), *Epalxiphora axenana* Meyrick, *Epiphyas postvittana* (Tortricidae); *Platyptilia falcatalis* Walker, (Pterophoridae); *Hierodons atychioides* (Butler), *Stathmopoda horticola* Dugdale (Oecophoridae), an unidentified psychid and possibly others (J.I. Townsend pers. comm.).

Xanthopimpla rhopaloceros Krieger (Hymenoptera: Ichneumonidae)

This species of parasitoid was initially established from small releases made in Nelson, but later it disappeared. Releases of reared adults were made at Kerikeri (by R.A. Cumber), Hamilton, Kaingaroa Forest, Rotorua, Nelson and near Christchurch during 1967-1973. R.A. Cumber (DSIR files) first confirmed establishment of this species at Paihia in 1973 and during the next few years it became very numerous and spread throughout the North Island. The species was observed to be common in Wellington in 1985 and in 1986 it was confirmed to be established in Nelson (Thomas unpublished). Attempts to establish *X. rhopaloceros* in Christchurch during 1972, 1978-1980 and again in 1984-1987 (from field collections of adults made by F.A. Gunson and J.R. Clearwater) have not been successful.

Glabridorsum stokesii (Cameron) (Hymenoptera: Ichneumonidae)

Glabridorsum (= *Gambrus*, = *Ischnus*) *stokesii* feeds as an ectoparasitoid on fresh archipine tortricid and oriental fruit moth pupae but later in its development becomes endoparasitic. It was successfully cultured and distributed to the same areas as *X. rhopaloceros* during 1967-1973. It became established at Appleby, Nelson in 1969/70 where it was also occasionally observed to parasitise codling moth. Adults have been observed in Nelson overwintering along with other Hymenoptera among the dead leaves on cabbage trees (*Cordyline* sp. (Agavaceae)) (Thomas unpublished). It became established in Northland, Auckland, Hamilton and Hawke's Bay and has been reported as the most numerous pupal parasitoid of the second summer generation of oriental fruit moth in Auckland (Russell 1987, Chapter 28). Collection of adults and redistribution to Christchurch in 1972 and 1979-80 failed to achieve their establishment. Further late spring releases in Christchurch in 1985 led to at least two field generations during the summer of 1985-86, but there is no recent evidence of establishment in Canterbury.

Brachymeria phya (Walker), *B. teuta* (Walker) (= *B. rubripes* Girault) and *Brachymeria* sp. (Hymenoptera: Chalcididae)

These species were all cultured successfully and released in Nelson, Christchurch, Auckland, Hamilton and Tauranga but the *Brachymeria* sp. culture died out in 1971 and establishment is not confirmed. *B. phya* and *B. teuta* successfully established in Nelson during 1968-73, but the species have not been recorded from field collections since 1975. One unconfirmed report of *B. teuta* was made north of Auckland (R. Emberson pers. comm.) in 1972 but no confirmation of establishment in any district has been made.

Evaluation

The introduction of *T. brevifacies*, *X. rhopaloceros* and *G. stokesii* has resulted in their successful establishment and natural spread, assisted by some redistribution. These species attack the late larval and pupal stages of the host's life cycle in which the native parasitoid fauna is depauperate. As yet there is only circumstantial evidence that they have contributed to the decline in abundance of pest archipine tortricids generally on a wide range of host plants. While *G. stokesii* has an impact on oriental fruit moth in the second summer generation in summerfruit orchards (Russell 1987) there is apparently little interaction of the three parasitoids with hosts on apple trees in Auckland (C.J. Green 1984).

Detailed studies of the impact of the parasitoids on the target pest population have failed to show any regulatory role (C.J. Green 1984) except perhaps for parasitism of *Cydia molesta* (Busck) by *G. stokesii* (Chapter 28). The circumstantial evidence of reduction in archipine tortricid populations has not been quantified. Leafrollers remain both abundant and key pests in orchards.

It was known from the outset that these parasitoids accepted a range of archipine tortricids as hosts but in the case of *T. brevifacies* this species has adapted to an additional range of hosts in other lepidopteran families (O.R. Green 1984) and J.I. Townsend (pers. comm.). *X. rhopaloceros* also parasitises a range of smaller tortricids in New Zealand, in addition to its normal archipine tortricid hosts.

Roberts (1986) expressed concern at the broad host range of these introduced Australian parasitoids, especially *T. brevifacies*, in New Zealand. This species tends to stalk caterpillars and is stimulated to oviposit through its host's movement and colour. It is very unlikely that any species accepted as a host by these introduced parasitoids will become extinct as a result of their activities, but some species in habitats occupied by the parasitoids have probably been reduced in abundance during the early phase of parasitoid establishment, as circumstantial evidence suggests. Native host species that have been affected in this way during the 'explosive' phase of parasitoid establishment will probably increase in numbers again once parasitoid numbers decline.

There can be no question that native hosts are parasitised, at least in some habitats, but there is no evidence that this is affecting the population dynamics of these species. No population studies of sufficient detail have been undertaken, nor has there been a systematic evaluation of the levels of parasitism caused by the introduced parasitoids.

In general terms the introduction and establishment of these parasitoids on pest tortricid species has been achieved. Movement of *T. brevifacies* and *X. rhopaloceros* has been from Northland southwards in the North island, and it is possible that all the species will in time adapt to cooler weather conditions prevailing in the South Island. During rearing of the pupal parasitoids *X. rhopaloceros* and *G. stokesii*, about 25% of the hosts were killed through feeding by the adult parasitoids which thus rendered them unsuitable for parasitisation. Host mortality was increased in this way. *G. stokesii* is now recognised as an important parasitoid of oriental fruit moth in New Zealand (Chapter 28) and is the most common introduced parasitoid of leafroller pupae in Nelson.

In Australia MacLellan (1973) recorded spiders, notably the theridiid *Achaearanea veruculata* (Urquhart), among the major array of predators of *E. postvittana* and Danthanarayana (1975a) considered the European earwig (Chapter 35) was also important. Predators already play a minor role in New Zealand and it is unlikely additional species will be considered for introduction for lightbrown apple moth control in this country.

Conclusions

Tortricid parasitoids were introduced to contribute to integrated control programmes for fruit pests, primarily by reducing the reservoir of pest leafrollers which invade orchards. In practice the impact of the introduced leafroller parasitoids has in the main occurred on hosts outside sprayed commercial orchards. C.J. Green (1984) recorded few of these parasitoids in an unsprayed Auckland apple orchard despite their being frequently observed in the surrounding area. Research conducted in Europe (Carl 1965, 1976) on tortricid parasitoids has established that an additional species, *Colpoclypeus florus* (Walker) (Eulophidae), warrants consideration for introduction to New Zealand. This species commonly attacks tortricid species in apple orchards and is widely distributed in Europe. *C. florus* was the most abundant parasitoid in European studies (Carl 1965, 1976) and it has been studied in detail by Dijkstra (1986). A range of parasitoids known from *E. postvittana* in England (D.V. Alford pers. comm.) may also warrant investigation for importation in the future.

No quantitative studies have examined the contribution of the introduced Australian parasitoids to regulation of leafroller or other host populations in New Zealand. This research is needed. The introduction of an additional larval parasitoid such as *C. florus*, which is common in European orchards is considered advantageous and would possibly provide an enhanced leafroller parasitoid fauna in the more southern regions of the South Island, if it could be established in New Zealand.

Literature Cited

Bellas, T.E.; Bartell, R.J.; Hill, A. (1983) Identification of two components of the sex pheromone of the moth, *Epiphyas postvittana* (Lepidoptera, Tortricidae). *Journal of chemical ecology* 9, 503-512.

Carl, K.P. (1965) Natural enemies of *Argyrotaenia pulchellana*. CIBC unpublished report. 18 pp.

Carl, K.P. (1976) Beobachtungen über Parasiten und Räber von *Adoxophyes orana* in den Jahren 1963 bis 1965. *Nötzlinge in Apfelanlegen, IOBC/WPRS*, 49-52.

Collyer, E.; van Geldermalsen, M. (1975) Integrated control of apple pests in New Zealand. 1. Outline of experiment and general results. *New Zealand journal of zoology* 2, 101-134.

Danthanarayana, W. (1975a) The bionomics, distribution and host range of the light brown apple moth, *Epiphyas postvittana* (Walk.) (Tortricidae). *Australian journal of zoology* 23, 439-451.

Danthanarayana, W. (1975b) Factors determining variation in the fecundity of light brown apple moth, *Epiphyas postvittana* (Walker) (Tortricidae). *Australian journal of zoology* 23, 439-451.

Danthanarayana, W. (1983) Population ecology of the light brown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Journal of animal ecology* 53, 1-33.

Dijkstra, L.J. (1986) Optimal selection and exploitation of hosts in the parasitic wasp *Colpoclypeus florus* (Hym., Eulophidae). Ph.D. Thesis, University of Wageningen, The Netherlands. 169 pp.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1932) The apple leaf-roller (*Tortrix postvittana* Walker). *New Zealand journal of science and technology* 14, 83-92.

Dumbleton, L.J. (1935) *Apanteles tasmanica* Cam., a braconid parasite of leafroller larvae. *New Zealand journal of science and technology* 17, 572-576.

Dumbleton, L.J. (1936) IV. The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Dumbleton, L.J. (1939) Contribution to the physical ecology of *Tortrix postvittana*, Walk. (Lep.). *Bulletin of entomological research* 30, 309-319.

Dumbleton, L.J. (1940) *Tortrix postvittana* Walk. and its parasites in Australia. *New Zealand journal of science and technology* A21, 322-336.

Early, J.W. (1984) Parasites and predators. Pp. 271-308 in Scott, R.R. (ed.) New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Evans, J.W. (1937) The light brown apple moth (*Tortrix postvittana* Walker). *Tasmanian journal of agriculture* 8, Supplement, 1-8.

Geier, P.W.; Briese, D.T. (1980) The light brown apple moth, *Epiphyas postvittana* (Walker): 3. Population dynamics and injuriousness to apples in an immature plantation of the Australian Capital Territory. *Australian journal of ecology* 5, 63-93.

Geier, P.W.: Briese, D.T. (1981) The light brown apple moth, *Epiphyas postvittana* (Walker): a native leafroller fostered by European settlement. Pp. 131-155 in Kitching, R.L.; Jones, R.E. (eds), The ecology of pests, Commonwealth Scientific and Industrial Research Organisation, Melbourne, Australia.

Green, C.J. (1984) Bionomics of *Epiphyas postvittana*, *Ctenopseustis obliquana*, *Planotortrix excessana* (Lepidoptera: Tortricidae) and *Stathmopoda 'skelloni'* (Lepidoptera: Stathmopodidae) on apple cv. 'Dougherty' in Auckland. Ph.D. Thesis, University of Auckland. 179 pp. + Appendices.

Green, O.R. (1984) New Zealand host and locality records for an introduced tortricid parasite, *Trigonospila brevifacies* (Diptera: Tachinidae). *New Zealand entomologist* 8, 69-71.

Hudson, G.V. (1928) The butterflies and moths of New Zealand. Ferguson & Osborn, Wellington, New Zealand. 386 pp. + plates.

MacCollom, G.B.; Read, E.M. (1971) A nuclear polyhedrosis virus of the light brown apple moth, *Epiphyas postvittana*. *Journal of invertebrate pathology* 18, 337-343.

MacLellan, C.R. (1973) Natural enemies of the light brown apple moth, *Epiphyas postvittana*, in the Australian Capital Territory. *Canadian entomologist* 105, 681-700.

Meyrick, E. (1937) *Tortrix postvittana* Walk. A species new to Britain. *Entomologist* 70, 256.

Miller, D.; Watt, M.N. (1915) Contributions to the study of New Zealand entomology, from an economical and biological stand point: no. 4 *Phorocera nefaria* Hutton; no. 5 – *Psychoda conspicillata* Hudson; no. 6 – *Syrphus ropalus* Walk.; no. 7 – *Phytomyza albiceps* Mg. (Diptera). *Transactions and proceedings of the New Zealand Institute* 47, 274-284.

Ramsay, G.W. (1963) Predaceous shield-bugs (Heteroptera: Pentatomidae) in New Zealand. *New Zealand entomologist* 3, 3-7.

Roberts, L.I.N. (1986) The practice of biological control - implications for conservation, science and the community. *The weta* 9, 76-84.

Russell, D.A. (1987) *Glabridorsum stokesii* (Cameron) Hymenoptera: Ichneumonidae) – a parasitoid of the oriental fruit moth (*Grapholita molesta*) in New Zealand. *New Zealand entomologist* 10, 26-38.

Stevens, P.S. (1988) Biological control of leafrollers (Lepidoptera: Tortricidae) on kiwifruit by the egg parasitoid *Trichogrammatoidea bactrae fumata* Nagaraja (Hymenoptera: Trichogrammatidae). Ph.D. Thesis, University of Auckland, Auckland, New Zealand. 125 pp.

Suckling, D.M.; Chapman, R.B.; Penman, D.R. (1984) Insecticide resistance in the light brown apple moth, *Epiphyas postvittana* Walker (Lepidoptera: Tortricidae): larval response to azinphosmethyl. *Journal of economic entomology* 77, 579-582.

Suckling, D.M.; Penman, D.R.; Chapman, R.B. (1986) Toxicity of insecticides to *Epiphyas postvittana* Walker (Lepidoptera: Tortricidae). *New Zealand journal of experimental agriculture* 14, 89-95.

Suckling, D.M.; Rogers, D.J.; Shaw, P.W.; Wearing, C.H.; Penman, D.R.; Chapman, R.B.; (1987) Monitoring azinphosmethyl resistance in light brown apple moth (Lepidoptera: Tortricidae) in New Zealand. *Journal of economic entomology* 80, 733-738.

Thomas, W.P. (1965a) Studies on *Epiphyas postvittana* (Walker) Lepidoptera, Tortricidae) and its parasitoid complex. M.Sc. thesis, University of Canterbury. 130 pp. and appendices.

Thomas, W.P. (1965b) A note on the life cycle of eugregarines inhabiting the alimentary canal of *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae). *New Zealand entomologist* 3, 42-46.

Thomas, W.P. (1968) An artificial diet for rearing the light brown apple moth *Epiphyas postvittana* (Walk.) (Lepidoptera: Tortricidae). *New Zealand entomologist* 4, 31-32.

Thomas, W.P. (1975) Additional notes on leafrollers. *Orchardist of New Zealand* 48, 354-355.

Tomkins, A.R. (1984) Tortricid moth pest management in Canterbury apple orchards. Ph.D. thesis, University of Canterbury, Lincoln College. 319 pp.

Wearing, C.H.; Thomas, W.P.; Dugdale, J.S.; Danthanarayana, W. (in press). Australian and New Zealand species. In van der Geest, L.P.S.; Evenhuis, H.H. Tortricoid pests, world crop pests. Elsevier Science Publishers.

Zondag, R. (1965) Insect pests of forest nurseries and young plantations in New Zealand. *Proceedings of the 13th International Congress of Entomology*, London, 1965, 674-675.

Eriosoma lanigerum (Hausmann), woolly apple aphid (Homoptera: Pemphigidae)

J.T.S. WALKER

Pest Status

The woolly apple aphid, *Eriosoma lanigerum* (Hausmann), is a serious pest of apple trees in both commercial orchards and in nursery plantings throughout the world. A nearctic species, *E. lanigerum* originated in eastern North America (Baker 1915) where the primary host is American elm, *Ulmus americana* L. (Patch 1912) but it is now cosmopolitan in its distribution. The importance of elm and the sexual cycle to the pest status of *E. lanigerum* on apple is greatly reduced because the asexual cycle continues year round on apple (Theobold 1920). Many different generic and specific names have been used for *E. lanigerum*, these are reviewed in Patch (1912). Commonly used names in early studies include *Aphis lanigera* Hausmann and *Schizoneura lanigera* Hartig.

In New Zealand the most common and characteristic form on apple is the wingless female which reproduces asexually. The aphids overwinter primarily as nymphs in the first instar, in spring these develop and give rise to 8-10 generations of aphids by late summer. Winged aphids may be found in colonies during February and March and may produce sexual forms but alate aphids do not appear to migrate to American elm in New Zealand (Dumbleton & Jeffreys 1938). The sexual cycle is therefore considered non-functional in New Zealand. The production of alate aphids is important as they are reproductively non-functional which can significantly reduce outbreaks of *E. lanigerum* in late summer. The lack of the sexual cycle is also significant as its absence limits aphid dispersal to the wandering behaviour of newly deposited nymphs, by wind and spread by cultural practices.

On susceptible apple trees, the aphid attacks roots as well as above ground parts of the tree where it may be found infesting all woody tissue, and is frequently associated with wounds caused by pruning or orchard machinery. Aphid feeding on host tissue results in the formation of galls, causing a loss in tree vigour. This aphid may also form colonies on fruit stems and in the calyx of apples, often infesting the core (Madsen & Hoyt 1957). Fruit may become contaminated by honeydew. Feeding is associated with the persistence and spread of a fungal disease, *Pezicula malicorticis* Jackson (Leach 1940).

Background

E. lanigerum was probably accidentally introduced into New Zealand on apple trees during early European settlement. Cottier (1935) and Miller *et al.* (1936) reported it as a major pest of apples prior to 1921. Control at that time was primarily insecticidal and based on nicotine sulphate (Esam 1919).

There are no early reports of endemic species of parasitoids attacking *E. lanigerum*. Subsequently, Collyer & Geldermalsen (1975) have identified endemic predators attacking dense infestations of aphids. These include two neuropteran predators *Micromus tasmaniae* Walker and *Drepanacra binocula* Newman (Hemerobiidae), but their numbers were restricted by a parasitoid, *Anacharis zealandica* Ashmead (Figitidae).

Rootstocks resistant to aphid attack have been developed at the East Malling Research Station in Great Britain and some of these are extensively used in New Zealand orchard plantings. Formerly the variety 'Northern Spy' was used as a rootstock but this has largely been replaced by resistant rootstocks of the 'Malling-Merton' series. Recently, aphid biotypes

have been reported attacking these rootstocks in several different countries (Rock & Zeiger 1974).

Importations, Releases and Recoveries

Aphelinus mali (Haldeman) (Hymenoptera: Aphelinidae)

Aphelinus mali was introduced into New Zealand from three locations in the U.S.A. (Washington State, Connecticut and Arkansas) in early 1921. Care was taken with this introduction to eliminate secondary parasitoids of *A. mali*. The initial releases failed with the exception of three males and two females and it was from these individuals that the subsequent release and distribution programme developed (Tillyard 1921). The initial release programme concentrated on the Nelson district and approximately 3,000 *A. mali* were liberated there during the 1921-22 season. By October 1922 it was also established in the Hawke's Bay district. During the 1922-23 season 33,000 were released throughout the country and in the 1923-24 season a further 90,000 parasitoids were released. *A. mali* was also shipped to Australia in 1923 for distribution in Queensland, Western Australia and Tasmania (DSIR files). By 1925, just four years after the introduction of *A. mali*, it was widespread throughout New Zealand, almost completely eliminating *E. lanigerum* in orchards (Cottier 1935, DSIR files).

Evaluation

Despite this initial success of the release programme, numerous correspondence was received between 1938 and 1942 indicating that some resurgence of *E. lanigerum* had occurred in many districts (DSIR files, Miller *et al.* 1936). Dumbleton & Jeffreys (1938) reviewed factors affecting the biological control of *E. lanigerum* by *A. mali* in New Zealand. They concluded that major factors influencing aphid outbreaks included variable activity of predaceous insects, disruption resulting from the application of insecticides and the removal of parasitoid infested prunings from orchards.

In commercial orchards sprays are normally applied to control *E. lanigerum* (Charles & Walker 1981, Charles & White 1984). Organophosphorus insecticide sprays provide considerable suppression of both aphid and parasitoid populations and so minimise biological control. Synthetic pyrethroid insecticide sprays are less toxic to both *E. lanigerum* and *A. mali* but aphid outbreaks may occur with this group of insecticides in New Zealand (Penman & Chapman 1980). In the absence of pesticides *E. lanigerum* is rarely a serious pest of apples in New Zealand and is adequately controlled by *A. mali*.

Conclusions

Biological control of *E. lanigerum* by *A. mali* in New Zealand has been highly successful. There is no requirement for any additional introduction of biological control agents to assist with the control of *E. lanigerum*. It may however, be appropriate to consider the introduction of more general aphid feeding predators, such as Chrysopidae, which also feed on *E. lanigerum* but have increased tolerances to certain orchard pesticides.

Literature Cited

Baker, A.C. (1915) The woolly aphis. *United States Department of Agriculture, report* 101, 1-55.

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control. *DSIR bulletin* 242, 51 pp.

Charles, J.G.; Walker, J.T.S. (1981) Mealybug control in apples. *Orchardist of New Zealand* 54, 252-253.
Charles, J.G.; White, V. (1984) Early season use of vamidothion against woolly apple aphid. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 241-244.
Collyer, E.; Geldermalsen, M. van (1975) Integrated control of apple pests in New Zealand I. Outline of experiment and general results. *New Zealand journal of zoology* 2, 101-134.
Cottier, W. (1935) Aphids affecting cultivated plants. *New Zealand journal of agriculture* 51, 26-31.
Dumbleton, L.J.; Jeffreys, F.J. (1938) The control of woolly aphis by *Aphelinus mali*. *New Zealand journal of science and technology* 20, 579-593.
DSIR, Entomology Division, file BC 1/4.
Esam, G. (1919) Control of red mite and woolly aphis in nursery stock. *New Zealand journal of agriculture* 18, 94-96.
Leach, J.G. (1940) Insect transmission of plant diseases. McGraw-Hill, New York. 615 pp.
Madsen, H.F.; Hoyt, S.C. (1957) The effects of spray chemicals on the local dispersal of woolly apple aphid. *Journal of economic entomology* 50, 402-406.
Miller, D.; Clark, A.F.; Dumbleton D. (1936) Biological control of noxious insects and weeds in New Zealand. *New Zealand journal of science and technology* 18, 579-593.
Patch, E.M. (1912) Elm leaf curl and woolly apple aphid. *Maine Agricultural Experiment Station bulletin* 203, 235-258.
Penman, D.R.; Chapman, R.B. (1980) Woolly apple aphid outbreak following the use of fenvalerate in apples in Canterbury, New Zealand. *Journal of economic entomology* 73, 49-51.
Rock, G.C.; Zeiger, D.C. (1974). Woolly apple aphid infests Malling and Malling-Merton rootstocks in propagation beds in North Carolina. *Journal of economic entomology* 67, 137-138.
Theobold, F.V. (1920) The woolly aphid of apple and elm. *Journal of pomology* 2, 73-92.
Tillyard, R.J. (1921) The introduction into New Zealand of *Aphelinus mali*, a valuable parasite of the woolly aphis. *New Zealand journal of agriculture* 23, 7-19.

Forficula auricularia L., European earwig (Dermaptera: Forficulidae)

W.P. THOMAS

Pest Status

The European or common earwig, *Forficula auricularia* L. was first reported in New Zealand by Smith (1898), who had received specimens from an Ashburton (Mid Canterbury) grower some two years prior to this date. The specimens had been found among greenhouse plants procured from Christchurch, at a location to which plants had been exported direct from London over many years. Hebard (1933) lists three female specimens from New Zealand deposited by A. Koebele in the collection of Dermaptera in the Californian Academy of Science around 1900, but no date is given.

According to Lamb & Wellington (1975), *F. auricularia* is native to Europe, western Asia and the northern fringe of Africa, and it has spread to most north and south temperate countries. It is now cosmopolitan (Hinks 1949). In New Zealand, the early spread of the European earwig was referred to by Thomson (1922). In the early period following establishment, it became very abundant in Central Otago but is now widely distributed in open lowland regions of the South Island and in parts of the North Island (Scott 1984).

The European earwig, which is omnivorous and nocturnal in habit, spasmodically invades houses (Thomson 1922, Muggeridge 1927). It causes feeding damage on vegetables, flowers, pollen and fruits and in Central Otago it was recognised as a serious pest of stonefruit (Thomson 1922). The active stages often enter ripening fruit of apples, peaches, apricots and nectarines (summerfruit) where they feed on the flesh and contaminate the inner tissues with excreta. Alford (1984) considered *F. auricularia* a minor pest in apple orchards but sometimes troublesome in blackcurrants, as occurs in New Zealand where some soft fruiting cultivars are grown. Damaged fruits may become infected by secondary fungal pathogens. Blackcurrant canes damaged by currant clearwing (*Synanthedon tipuliformis* (Clerck)) often provide shelter for earwigs (Scott 1984). In England, apple crops may show up to 9.9 % European earwig feeding damage to harvested fruit (Phillips 1983). In North America, the European earwig is recorded as feeding on ripe fruit, garbage and plants, which include: dahlias, zinnias, butterfly bush, hollyhock, lettuce, celery, potatoes, seedling beans, beets and sweetcorn flower silks (Anonymous 1970) but this list is by no means complete or representative of all countries.

Besides feeding on plants or fruit, the European earwig is also carnivorous, and preys on a wide range of insect and mite species. This useful role questions the advisablity of attempting biological control. In Australia, Danthanarayana (1983) considered spiders and *F. auricularia* as important predators of the light brown apple moth *Epiphyas postvittana* (Walker) by feeding on larvae within the leaf rolls. This activity occurs also in New Zealand. Other prey recorded include the codling moth *Cydia pomonella* (L.) (Glen 1975) (see Chapter 28), cereal aphids (Sunderland & Vickerman 1980), hop aphids (Buxton & Madge 1976, Madge & Buxton 1976) and lucerne aphids (M.W. Stufkens pers. comm.), mites and scale insects.

The life cycle of the European earwig in New Zealand conforms to the pattern in Europe (Muggeridge 1927, Miller 1944). After mating in the autumn both sexes construct and hibernate in subterranean nests until the first batch of eggs is laid in early spring. Following this the male is forced out and the female alone remains in the nest to brood the eggs. Without such care the eggs fail to hatch (Lamb 1976). The young nymphs, which shelter during the day, emerge at night from the soil to feed on the aerial portions of plants. The

female broods over her young until they reach the second instar when the nest is normally abandoned. A second, or more rarely a third batch of eggs may be laid and brooded over. Detailed accounts of the life history for *F. auricularia* are provided by Phillips (1981) and Lamb & Wellington (1975) for England and Vancouver, British Columbia, respectively.

Various measures were adopted in the past for controlling earwigs in fruit or flower crops in New Zealand. These included the use of simple traps, poison baits, fumigants and chemical dusts (Muggeridge 1927). In dry areas where baits may not be effective, the recommendation from the United States Department of Agriculture is for dusting or spraying of infested places with chlordane (Anonymous 1970).

Background

The rapid spread and early abundance of the European earwig in New Zealand, together with the serious depredations it caused to stonefruit in the major production area of Central Otago, initiated the investigation and importation by the Cawthron Institute of two dipterous species of parasitoids (Tachinidae) from England in 1923 (Tillyard 1926, DSIR files). These were; 1. *Triarthria setipennis* Fallén imported as *Bigonicheta* (= *Digonochaeta*) *spinipennis* (Meigen) (= *B. setipennis* (Fallén)); (nomenclature provided by British Museum (Natural History)). 2. *Ocytata* (= *Rhacodineura*) *pallipes* (Fallén) (= *R. antiqua*) Meigen (aberrant form). Natural enemies already present in New Zealand were recorded by Miller (1971) as birds, threadworms, fungi and ground beetles.

T. setipennis, in the sense used above, now includes the 'northern' and 'southern' forms described as separate species by Phillips (1983). Verification of the identity of the species, (*T. setipennis* and *O. pallipes*) introduced into New Zealand was provided by J.S. Dugdale using the description of the adults in van Emden (1954).

Descriptions of the anatomy of the life history stages and biology of the these two tachinids are provided by Thompson (1928). *T. setipennis* is recorded as a parasitoid of several species of lepidopterous larvae, but Thompson (1928) suggests its host range requires verification. *T. setipennis* deposits its egg, containing the fully developed embryo, in the vicinity of resting earwigs. The egg hatches immediately following deposition and the maggot searches out a host and tunnels directly through the integument into the body (Phillips 1983). In contrast, the minute eggs of *O. pallipes* are laid in the vicinity of earwig feeding damage. An egg which is ingested hatches during its passage through the gut of the host. Both these obligatory, univoltine parasitoids emerge as fully developed larvae from their adult hosts and then pupate.

Importations, Releases and Recoveries

Initial consignments of the parasitoids were arranged through courtesy of A.D. Imms of the Imperial Bureau of Entomology in England during 1923 to 1925. In the autumn of 1926, W.M. Davies of the Rothamsted Experiment Station (England) continued the search for tachinid parasitoids for shipment to New Zealand (Davies 1927). An interesting association between the damage caused by a noctuid lepidopteran *Dasypolia templi* (Thunberg) to the common *Heracleum sphondylium* L. (hogweed) in England and the shelter the hollowed out stems of this plant provided, enabled a methodology for field collection of large numbers of earwigs, *T. setipennis* and hyperparasitoids (Davies 1927). The tachinid puparia obtained were packed in moist sphagnum moss and shipped to New Zealand in cool storage.

Details of the consignments of *O. pallipes* and *T. setipennis* received at the Cawthron Institute, Nelson, have been summarized from a comprehensive report by E.S. Gourlay (DSIR files).

Ocytata pallipes (Fallén) (Diptera: Tachinidae)

The first consignment of tachinids received in December 1923 comprised 1,404 earwigs inclusive of 75 unemerged tachinid puparia and 28 emerged *O. pallipes* adults. The *O. pallipes* were placed in observation cages with food partially eaten by locally collected earwigs. After oviposition by the flies, the food was returned to the earwig cages. Apple and dandelion were used as food for the earwigs, but large numbers of uningested eggs were wasted as the food dried out.

From this shipment a total of 43 male and 29 female adult *O. pallipes* emerged. Rearing of the first tachinid generation produced 136 puparia, from which 64 males and 32 females emerged. In the second generation only 13 puparia were produced, which gave rise to four adult males (some unhealthy) and a single female. This population died out and no releases were made.

Triarthia setipennis Fallén (Diptera: Tachinidae)

Although *T. setipennis* (= *Bigonicheta spinipennis* (Meigen) was reportedly present in the first consignment of tachinids received in New Zealand (above), none emerged (DSIR files). This parasitoid did however comprise the bulk of the material consigned intermittently from England to New Zealand during 1923 to 1929. Table 35.1 gives the composition of the parasitoid consignments for this period together with rearing information for *T. setipennis*.

In New Zealand, reported releases included a total of seven individuals of *T. setipennis* released in Central Otago in early 1929 and four males and 10 females at Nelson during March and April of the same year (DSIR files). Dumbleton (1936) reported an additional release in 1933 but verification of this has not been possible. Also Tillyard (1926) indicated that earlier releases, other than those reported by E.S. Gourlay (DSIR files) were made in Central Otago in 1923. No confirmation of this information is available.

There are no reports of either *T. setipennis* or *O. pallipes* having established in New Zealand. Apparently no releases of the latter were undertaken (Dumbleton 1936, DSIR files).

Table 35.1 Composition of consignments of *Triarthria setipennis* received and emerged at Nelson, together with rearing and release information.

Consign. No. & Origin	Date rec'd	No. of puparia received	No. Emerged Male	No. Emerged Female	NZ F1 Generation Male	NZ F1 Generation Female	Release Information
1 CIE*	Dec. 1923	150	135	77	9	3	None released
2 CIE	Jan. 1924	149					
3 CIE	Dec. 1926	500	224	237	1	0	None released
4 CIE	Dec. 1926	183					
5 R*	Dec. 1928	209 (stored 1 mth in coolstore)	73	82	0	0	None released
6 R	Feb. 1928	34 (stored successfully for up to 1yr)	16	10	0	0	Releases were made in C. Otago
7 FR*	Nov. 1928	245	28	36	0	0	and Nelson from flies
8 FR	Dec. 1928	249	31	32	0	0	that emerged from these
9 FR	Mar. 1929	200	29	29	0	0	importations

*CIE – CABI Institute of Entomology; R – Rothamsted; FR – Farnham Royal

Evaluation

O. pallipes was not released and *T. setipennis* apparently failed to establish in New Zealand.

The principal reasons for the failure of successful breeding of *T. setipennis* were the wastage of adults through mating failure and the levels of hyperparasitism of the tachinid puparia received, by *Dibrachys cavus* (Walker) (Pteromalidae) and *Phygadeuon vexator* (Thunberg) (Ichneumonidae) (DSIR files).

Levels of parasitism reported overseas for these tachinid species are also not encouraging (Davies 1927, Phillips 1983). From the total number of earwigs (5,800) collected during September-October 1926 for shipment to New Zealand, (Davies 1927) some 5% were parasitised by tachinids. This is a relatively low figure. Phillips (1983) reported on orchard studies at Bristol in 1979 where total parasitism for the first brood was 13% and 3.9% from the second. In Newfoundland, where *T. setipennis* was introduced from British Columbia during 1951 to 1953, parasitism remained at extremely low levels. These releases were followed by others originating from Sweden and Switzerland and in 1973 parasitism reached 16.4% (Morris 1984). This was the maximum level reported during a study from 1969 to 1978 and Morris (1984) concluded that the considerable reduction in earwig populations in the study area since 1972 was due in part to this tachinid.

In New Zealand, however, as reported by Morris (1984) for Canada, populations of *F. auricularia* have decreased considerably (letter by D. Miller DSIR files). The reasons for this are unknown, but Miller (1971) implies some population control by birds, threadworms, fungi and ground beetles.

This author has found that populations in Canterbury are often parasitised by gregarines and the nematode *Mermis subnigrescens* Cobb. The latter appears to sterilize adults and Wilson (1971) suggests it suppresses population numbers in Canada.

Soon after it was introduced to New Zealand, the hedgehog was distributed to Central Otago as a possible earwig control measure (Muggeridge 1927). It is not known if this predator is important in earwig control in that region, but Campbell (1973) reported high European earwig predation by this predator in Canterbury. There is also evidence of high levels of earwig predation by the brown owl *Athene noctua* (Scopoli) (Muggeridge 1927).

Conclusions

The European earwig remains relatively common in New Zealand but through the use of modern, broad spectrum organic pesticides is not a serious pest in orchards or commercial gardens. Dwellings are occasionally invaded but no regular control measures to prevent this occurrence are necessary. Since there has been a general reduction in European earwig populations in New Zealand, and recorded parasitism levels overseas are relatively low, there is no requirement currently to re-import parasitoids for this insect.

Acknowledgements

To M.W. Stufkens for information on predation by the European earwig on lucerne aphids and J.S. Dugdale for confirming the identity of the tachinid species introduced into New Zealand.

Literature Cited

Anonymous (1970) The European earwig. How to control it around the home. *Home and garden bulletin, revised, United States Department of Agriculture* 75, 8 pp.

Alford, D.V. (1984) A colour atlas of fruit pests their recognition biology and control. Wolfe Publishing Ltd, Scotland. 320 pp.

Buxton, J.H.; Madge, D.S. (1976) The evaluation of the European earwig *Forficula auricularia* as a predator of the damson-hop aphid *Phorodon humuli*. I. Feeding experiments. *Entomologia experimentalis et applicata* 19, 109-114.

Campbell, P.A. (1973) Feeding behaviour of the European hedgehog *Erinaceus europaeus* L. in a New Zealand pasture. Ph.D. thesis, Lincoln College, University of Canterbury. 230 pp. + appendices.

Danthanarayana, W. (1983) Population ecology of the light brown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Journal of animal ecology* 52, 1-33.

Davies, W.M. (1927) Methods for collecting parasites of earwigs. *Bulletin of entomological research* 17, 347-350.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1936) IV. The biological control of fruit pests in New Zealand. Pp. 588-592 in Miller, D.; Clark, A.F.; Dumbleton, L.J. Biological control of noxious insects and weeds in New Zealand. *New Zealand journal of science and technology* 18, 579-593.

Glen, D.M. (1975) The effects of predators on the eggs of codling moth *Cydia pomonella*, in a cider-apple orchard in south-west England. *Annals of applied biology* 80, 115-135.

Hebard, M. (1933) Dermaptera in the collection of the Californian Academy of Science. *Pan-Pacific entomologist* 9, 140-144.

Hinks, W.D. (1949) Some earwigs (Dermaptera) from New Zealand. *Proceedings of the Royal Entomological Society of London* 18, 201-206.

Lamb, R.J. (1976) Parental behaviour in the Dermaptera with special reference to *Forficula auricularia* (Dermaptera: Forficulidae). *Canadian entomologist* 108, 609-619.

Lamb, R.J.; Wellington, W.G. (1975) Life history and population characteristics of the European earwig, *Forficula auricularia* (Dermaptera: Forficulidae), at Vancouver, British Columbia. *Canadian entomologist* 107, 819-824.

Madge, D.S.; Buxton, J.M. (1976) The evaluation of the European earwig *Forficula auricularia* as a predator of the damson-hop aphid *Phorodon humuli*. II. Choice of prey. *Entomologia experimentalis et applicata* 19, 221-226.

Miller, D. (1944) Garden pests in New Zealand and how to control them. Whitcombe and Tombs, Christchurch, Auckland. 2nd edition revised and enlarged. 149 pp.

Miller, D. (1971) Common insects in New Zealand. A.H. & A.W. Reed Ltd, Wellington, Auckland. 178 pp.

Morris, R.F. (1984) *Forficula auricularia* L., European earwig (Dermaptera: Forficulidae) Pp. 39-40 in Kelleher, J.S.; Hulme, M.A. (eds) Biological control programmes against insects and weeds in Canada 1969-1980. Commonwealth Agricultural Bureaux, Farnham Royal, U.K.

Muggeridge, J. (1927) The European earwig; its habits and control. Some recent experimental work in New Zealand. *New Zealand journal of agriculture* 34, 395-401.

Phillips, M.L. (1981) The ecology of the common earwig *Forficula auricularia* in apple orchards. Ph.D. thesis, University of Bristol. 246 pp.

Phillips, M.L. (1983) Parasitism of the common earwig *Forficula auricularia* (Dermaptera: Forficulidae) by tachinid flies in an apple orchard. *Entomophaga* 28, 89-96.

Scott, R.R. (1984) Berryfruit pests. Pp. 11-31 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury.

Smith, W.W. (1898) *Forficula auricularia* in New Zealand. *Entomologist's monthly magazine* 34, 162.

Sunderland, K.D.; Vickerman, G.P. (1980) Aphid feeding by some polyphagous predators in relation to aphid density in cereal fields. *Journal of applied ecology* 17, 389-396.

Thomson, G.M. (1922) The naturalisation of animals and plants in New Zealand. Cambridge University Press, Cambridge, U.K. 607 pp.

Thompson, W.R. (1928). A contribution to the study of the dipterous parasites of the European earwig (*Forficula auricularia* L.). *Parasitology* 20, 124-158.

Tillyard, R.J. (1926) History of the introduction of beneficial insects into New Zealand. *Proceedings of the Pan-Pacific science congress, Australia, 1923* 1, 383-390.

van Emden, F.I. (1954) Handbooks for the identification of British insects, Diptera, Cyclorrhapha. *Entomological society of London* 10, 4a. 133 pp.

Wilson, W.A. (1971) Nematode occurrence in Ontario earwigs (Nematoda: Dermaptera). *Canadian entomologist* 103, 1045-1048.

Icerya purchasi Maskell, cottony cushion scale (Homoptera: Margarodidae)

C.F. MORALES and J. BAIN

Pest Status

Icerya purchasi Maskell, a native of Australia, became a very serious pest of citrus in California and South Africa in the 1870s (Ebeling 1958). It was first found in New Zealand on kangaroo acacia in Auckland in 1877 (Maskell 1879). It is now present in most subtropical, tropical, and many of the temperate areas of the world (Bartlett 1978). It can be a serious pest on a wide range of wild and cultivated plants, especially species in the genera *Acacia*, *Citrus*, *Casuarina* and *Pittosporum*. It is notable for its wide climatic tolerance and its severe effect on its host plants (Bartlett 1978).

It is usually found on twigs and branches but rarely on fruit or flowers, and in heavy infestations the plants appear to be covered with snow. Injury to plants is similar to that of other sap sucking insects, causing defoliation, fruit drop, and debility of the plant. The excretion of honey dew by the scales causes the growth of sooty mould fungus.

Background

I. purchasi was first noted to be causing severe damage in New Zealand in about 1883 (Anonymous 1889b). Damage was particularly severe in Nelson, Napier and Auckland and it was noted (Anonymous 1889b) that in Auckland 'considerable damage had been done, including the entire loss of Mr Reader Wood's valuable lemon grove...'. However, it was also noted, at least in some localities such as Wairoa South and Napier, that the scale was dramatically being brought under control by a small coccinellid beetle (Anonymous 1889b, Anonymous 1891b). At first, the coccinellid was thought to be a native species (Maskell 1890) but it proved to be *Rodolia cardinalis* (Mulsant) (Coleoptera: Coccinellidae) a rare Australian species. *R. cardinalis* was first discovered in New Zealand at Wairoa South (near Auckland) and was evidently not known to New Zealand entomologists. Presumably it was self-introduced from Australia with its host, *I. purchasi* (Anonymous 1889b, Wight 1890a).

R. cardinalis feeds principally on *I. purchasi* and other *Icerya* spp. as well as other Coccidae such as *Gueriniella serratulae* (F.) and *Drosicha corpulenta* (Kuwana). It has also been used in the successful control of *Icerya seychellarum* (Westwood), *I. aegyptiaca* (Douglas), *I. montserratensis* Riley & Howard and *I. palmeri* Riley & Howard (Bartlett 1978). It has been successfully introduced and has given good control of *I. purchasi* in more than 50 countries with climates ranging from temperate to desert or tropical (Bartlett 1978). Its ease of establishment is well illustrated by the fact that it was established in Peru through the release of just four adults (Bartlett 1978). *R. cardinalis* has two to two and a half generations for each generation of its host. In New Zealand, Kirk (1894) reported that the egg took five to seven days to hatch, the larval stages lasted 18-25 days and the pupal stage eight to nine days.

In about 1890 it was noted that *I. purchasi* was on the increase again and that *R. cardinalis* was very scarce and almost impossible to find (Anonymous 1891b). The scale insect was then causing severe damage to citrus orchards in Whangarei and after considerable searching, about 100 *R. cardinalis* were collected in Auckland and sent to Whangarei to control the scale infestation (Anonymous 1891d). It was because of fears expressed that *R. cardinalis* might die out in New Zealand that it was recommended that more be imported from overseas

and that other natural enemies of *I. purchasi* be introduced to augment the ladybird (Anonymous 1891c). *R. cardinalis* was reintroduced along with another *Rodolia* species, chloropid flies and *Cryptochetum iceryae* (Williston) (Diptera: Agromyzidae).

Cryptochetum iceryae was the first parasitoid known to attack *I. purchasi* in Australia (Quayle 1938). Its eggs are deposited singly in its host; second instar female scales are preferred but adult females and male stages can be attacked. *C. iceryae* was successfully introduced into California in 1888 and is an effective control agent of *I. purchasi* in the cooler, coastal areas (Bartlett 1978). It has been introduced into ten different countries but successful establishment has been achieved in only five cases (Bartlett 1978).

Valentine (1967) records that *Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae) is a predator of *I. purchasi* but there is no further information about its impact on scale populations. *C. undecimpunctata* was introduced into New Zealand from England in 1874 to control aphids (Chapter 11, Dumbleton 1936), but its usefulness is limited because it is parasitised by a small braconid wasp, *Dinocampus coccinellae* (Schrank) (Miller 1971).

The control of *I. purchasi* by *R. cardinalis* is hailed as a very successful biological control project in the U.S.A. It is interesting to note that the vast majority of the *R. cardinalis* that were sent to California were collected in Napier, New Zealand, not in Australia (Anonymous 1889b, Koebele 1890, Wight 1890b). This is contrary to what is generally reported in standard biological control texts (e.g. Huffaker 1971).

Importations, Releases and Recoveries

Cryptochetum iceryae (Williston) (Diptera: Agromyzidae)

In 1888 some *Cryptochetum iceryae* were sent by Mr Crawford, Adelaide, South Australia to New Zealand (Anonymous 1891c) (Table 36.1) and shortly afterwards, arrangements were made to send this fly to Mr Hamilton in Napier (Wight 1889). Another consignment of *I. purchasi* parasitised by *C. iceryae* was sent to Nelson from New South Wales in 1922 by L. Gallard (DSIR files). It was noticed that, as well as the flies, chalcidoid wasps had emerged in transit. These were suspected to be hyperparasitoids of *C. iceryae*, and the releases onto infested *Acacia* sp. trees at the Cawthron Institute, Nelson, were segregated to prevent the establishment of the chalcidoids. There are no records of the chalcidoids becoming established in New Zealand. In 1889 *I. purchasi* was recorded 'giving much trouble' at Nelson although it was noted that it was kept somewhat in check 'by an importation of lestophonus flies from Australia'. These 'lestophonus' flies were *C. iceryae*.

Dumbleton (1936) states that the introduction and establishment of *C. iceryae* was attempted in 1925 but without success. This would seem to imply that Dumbleton (1936) was unaware of the 1888 and 1922 introductions. Miller (1950) says that *C. iceryae* was accidentally introduced but does record its establishment here. Specimens of *C. iceryae* have been recovered from Northland, Auckland, Tauranga, Wanganui, Nelson and Canterbury (Dumbleton 1940, Harrison 1959). The specimens with the earliest recovery date are from Tauranga in 1937 (New Zealand Arthropod Collection (NZAC)).

Rodolia cardinalis (Mulsant) (Coleoptera: Coccinellidae)

In about 1891, C.V. Riley, State Entomologist, sent *R. cardinalis* (of Australian origin) from California to a fruit growers organisation in Nelson (Anonymous 1891c, Riley 1891) to augment the resident population. In 1894, *R. cardinalis* was first introduced directly from Australia (Dumbleton 1936). In the following years this beetle was distributed around New Zealand where there were outbreaks of *I. purchasi*. In 1922, 12 *R. cardinalis* from Tauranga were liberated in Nelson, and in the same year 29 larvae and two pupae of *R. cardinalis* were sent by L. Gallard in Australia and in 1926, 81 larvae, 11 pupae and nine adults were released on *Icerya* infested trees around urban Nelson. *R. cardinalis* has been recovered

from Auckland, Rotorua, Hawke's Bay, Wanganui and Nelson (NZAC, Forest Research Institute collection).

Rodolia sp. (Coleoptera: Coccinellidae)

Eighty *Rodolia* sp., probably *R. iceryae* Janson (Bartlett 1978), were imported from South Africa in 1887 and released in Nelson (Anonymous 1889c, Maskell 1890) but they did not become established (DSIR files).

Table 36.1 Main importations of natural enemies into New Zealand and redistributions throughout the country to control *Icerya purchasi*

Date	To	From	Natural enemy	Reference
Before 1888	Self introduced to New Zealand	Australia	*Rodolia cardinalis*	Wight 1890a
1887	Nelson	South Africa	*Rodolia* sp.	Maskell 1890
1888	Nelson	Australia	*Cryptochetum iceryae*	Anon. 1889, Anon. 1891b, 1891c
1888	New Zealand	Australia	*C. iceryae*	Wight 1888 Anon. 1889
1889	Hawke's Bay	Australia	*C. iceryae*	Wight 1889
1891	Nelson	California (Australian origin)	*R. cardinalis*	Anon. 1891b Riley 1891
1891	Whangarei	Auckland	*R. cardinalis*	Anon. 1891c
1893	Australia Nelson Blenheim South Africa	Whangarei	*R. cardinalis*	Wight 1893
1894	New Zealand	Australia	*R. cardinalis*	Dumbleton 1936
1896	Auckland	Wellington	*R. cardinalis*	Kirk 1896
1922	Nelson	Tauranga	*R. cardinalis*	DSIR files
1922-23	Nelson	Australia	chloropid flies	DSIR files
1922	Nelson	New South Wales	*C. iceryae* + chalcid wasps	DSIR files
1922	Nelson	New South Wales	*R. cardinalis*	DSIR files
1925	New Zealand	Australia	*C. iceryae*	Dumbleton 1936
1926	Nelson	New South Wales	*R. cardinalis*	DSIR files

Chloropid flies (Diptera: Chloropidae) During the 1922-23 season 36 *I. purchasi*, supposedly parasitised by chloropid flies, were received from Australia. Nothing emerged from this shipment (DSIR files).

Evaluation

There is no doubt that the introductions of *R. cardinalis* and *C. iceryae* resulted in excellent control of *Icerya purchasi* in New Zealand. No detailed evaluations of these natural enemies have been carried out in New Zealand, but it is generally understood that the coccinellid is the major controlling agent (e.g. Scott 1984). This agrees with world-wide experience where in the 50 or so countries where *I. purchasi* is a pest of citrus it is controlled mainly by *R. cardinalis* (Clausen 1978).

Conclusions

Icerya purchasi is no longer considered to be a serious pest in New Zealand and does not warrant further consideration for biological control.

Literature Cited

Anonymous (1889a) Mr Crawford's parasite of *Icerya*. *New Zealand country journal* 13, 63-64.

Anonymous (1889b) *Icerya purchasi*. *New Zealand country journal* 13, 497-500.

Anonymous (1889c) An African ladybird introduced into New Zealand. *Insect life* 1, 259-260.

Anonymous (1891a) Entomological notes. *Icerya purchasi* in the north. *New Zealand country journal* 15, 28-32.

Anonymous (1891b) Entomological notes. *Vedalia cardinalis*-(ladybird). *New Zealand country journal* 15, 139-141.

Anonymous (1891c) Entomological notes. Present aspect of *Icerya* and *Vedalia* in New Zealand. *New Zealand country journal* 15, 247-248.

Anonymous (1891d) A ladybird hunt. *New Zealand farmer* 11, 139.

Bartlett, B.R. (1978) Coccidae. Pp. 132-136 in Clausen, C.P. (ed.) Introduced parasites and predators of arthropod pests and weeds: a world review. *United States Department of Agriculture, Agricultural Research Service, Agricultural handbook* 480.

Clausen, C.P. (1978) Biological control of citrus insects. Pp. 274-317 in Reuther, W. *et al.* (eds) The citrus industry volume iv. Division of biological sciences, University of California, Berkeley, U.S.A.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Dumbleton, L.J. (1940) Australian parasites of *Eriococcus coriaceus* Maskell. *New Zealand journal of science and technology* 22, 102-108.

Ebeling, W. (1958) Subtropical fruit pests. California University Division of Agricultural Sciences publications. 436 pp.

Harrison, R.A. (1959) Acalypterate Diptera of New Zealand. *DSIR bulletin* 128, 382 pp.

Huffaker, C.B. (ed.) (1971) Biological control. Plenum Press, New York. 511 pp.

Kirk, T.W. (1894) *Report of the Department of Agriculture*, 47-106.

Koebele, A. (1890) Report on the fluted scale of the orange and its natural enemies in Australia. *Bulletin of the Bureau of the Entomology Department of the United States Department of Agriculture* 21, 9-32.

Maskell, W.M. (1879) On some Coccidae in New Zealand. *Transactions and proceedings of the New Zealand Institute* 11, 228-230.

Maskell, W.M. (1890) *Icerya purchasi* and its insect enemies in New Zealand. *Entomologists monthly magazine* 26, 17-19.

Miller, D. (1950) Catalogue of the Diptera of the New Zealand sub-region. *DSIR bulletin* 100, 194 pp.

Miller, D. (1971) Common insects in New Zealand. A.H. & A.W. Reed, Wellington, New Zealand. 179 pp.

Quayle, H.J. (1938) Insects of citrus and other subtropical fruits. Comstock Publishing Company Inc., Ithaca, New York. 583 pp.

Riley, C.V. (1891) Some *Icerya* and *Vedalia* notes. *Insect life* 37, 439-441.

Scott R.R. (ed.) (1984) New Zealand pests and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Wight, R.A. (1888) *Icerya purchasi*. *New Zealand country journal* 12, 422-423.

Wight, R.A. (1889) *Icerya purchasi*. *New Zealand country journal* 13, 215-18.
Wight, R.A. (1890a) Entomological notes. *New Zealand country journal* 14, 148-57.
Wight, R.A. (1890b) Mr. Koebele's visit to Australia and New Zealand. *New Zealand country journal* 14, 224-226.
Wight, R.A. (1893) *Vedalia cardinalis*. *New Zealand country journal* 17, 256.

Oemona hirta (F.), lemon tree borer (Coleoptera: Cerambycidae)

J.R. CLEARWATER

Pest Status

Oemona hirta (F.), lemon tree borer, is an endemic longhorn beetle found throughout New Zealand. The first scientific collection was made by Sir Joseph Banks on the voyages of Captain James Cook (1769-1774) and it was subsequently described by Fabricius in 1775 (Dye 1950). The life history has been briefly described by Clearwater (1981).

Linsley (1959) suggests that borers which attack living wood tend to be host specific, while species that are able to colonise many hosts prefer dead wood. *O. hirta* is therefore unusual in that it is most frequently found in the living wood of a great number of host species. Spiller & Wise (1982) list 35 native or exotic hosts. Twelve additional species are found in Dye's (1950) list. G. Kuschel (pers. comm.) has obtained *O. hirta* larvae from species of the genera *Macropiper*, *Schefflera*, *Sophora*, *Avicennia*, *Muehlenbeckia* and *Parsonsia*. I have obtained larvae from *Solanum aviculare* Forster f., *S. mauritianum* Scopoli and *Cupressus macrocarpa* Gordon. These lists are unlikely to describe the full host range of this borer species.

The activity of the boring larvae damages the framework of the host tree. When the load on a citrus tree increases as fruits develop, major limbs may collapse. Damage of this sort is difficult to quantify and economic damage thresholds have not been determined. Citrus growers have been concerned about chronic damage to their trees since the 1930s (Clearwater & Muggleston 1985). Grapevines suffer noticeable trunk damage, but the support wires used prevent collapse of the limbs.

Background

Gourlay (1930) records the endemic parasitoid *Xanthocryptus novozelandicus*? Dalla Torre (= *Mesostenus albopictus* Smith) (Ichneumonidae) from larvae of *O. hirta* and *Aspicolpus hudsoni* Turner (Braconidae) from larvae of *Oemona* sp. *X. novozelandicus* is frequently captured at Auckland, Gisborne, Kerikeri, Katikati and elsewhere. A single *Aspicolpus hudsoni* cocoon was reported by Dye (1950) but trapping in the same region has failed to reveal the continued presence of this species (Clearwater & S.J. Muggleston unpublished).

X. novozelandicus reaches peak numbers in late summer. Malaise trap records show that the flight activity of *X. novozelandicus* peaks in January and February. Samples of borer larvae collected from an Auckland citrus orchard in the spring showed low (0.8%) parasitism compared with February and March samples (8.8-26.4%) (Clearwater & Muggleston unpublished). Growth of the parasitoid larva in summer is very rapid (an early instar larva observed in the laboratory completed growth and pupated in only 10 days). Dye (1950) suggested that this parasitoid passes the winter as a diapausing pupa.

Apart from mortality caused by *X. novozelandicus*, and minimal predation by the many ant species present in a citrus orchard, the remaining mortality of up to 35% observed in the field is unexplained (Table 37.2).

The lemon tree borer is a very difficult target for an insecticide. Eggs are concealed in crevices in the bark. When the larvae hatch, they chew through the egg shell directly into the wood (Dumbleton 1937) where they are well protected from the action of insecticides.

The egg-laying female is strongly attracted to freshly cut branches and can be deterred by application of paints containing insecticide (Clearwater & Muggleston 1985). This method is labour intensive and unlikely to be employed to a great extent.

Releases and Recoveries

No species have been imported for biological control of this pest. Exotic parasitoids of the Cerambycidae have a wide host range which may include non-pest species in New Zealand. This has restricted present research to agents which can be directed specifically against *O. hirta*.

The biological control potential of three species of parasitic nematodes already present in New Zealand has been investigated (Clearwater & Wouts 1980, Clearwater, W. Wouts, S.J. Muggleston & K.L. Wildish unpublished). The nematodes were cultured and applied as a spray or injected through frass holes into borer burrows. The species chosen were *Steinernema bibionis* (Bovien) Wouts, Mráček, Gerdin & Bedding (collected from soil, One Tree Hill, Auckland), *Steinernema feltiae* (Filipjev) Wouts, Mráček, Gerdin & Bedding (collected from soil, Methven, mid-Canterbury) and *Heterorhabditis heliothidis* (Khan, Brooks & Hirschmann) Poinar, Thomas & Hess (collected from soil, Auckland City).

Entomophagous nematodes, although generally non-selective in their action, can be applied selectively if information on the seasonal patterns of the borer and the ichneumonid is available. Application of the nematodes can be timed for the season when most of the ichneumonid population is cocooned. Kaya & Hotchkin (1981) have found that the pore-free layer of silk within the cocoons of ichneumonids acts as a mechanical barrier to nematodes.

Initial laboratory trials with nematode (*S. feltiae*) suspensions injected into burrows, either through frass ejection holes or through a section of the burrow exposed by secateurs, were very promising. One month after treatment, most of a control group were alive (82%), while more than 90% of three groups treated with nematodes had died (Clearwater & Wouts 1980). A second series of experiments at Kerikeri revealed that 60% and 67% of larvae survived opening of the tunnel and inundation with water compared with 0 and 3% survival of larvae flooded with an aqueous solution of *S. feltiae*.

Table 37.1 Mortality of *Oemona hirta* larvae following application of nematodes or insecticide by injection or spraying. Trials were carried out at Katavo Orchard, Katikati, and Puketutu Island, Auckland, in 1981 (N = number of larvae)

Treatment	Katavo Orchard		Puketutu Island	
	% killed or missing	N	% killed or missing	N
Control (water injected)	22	49	57	95
Acephate (75 g ai/100 l) injected	45	47	66	91
Nematodes (*S. feltiae* 106/l) sprayed	42	53	66	106
Nematodes (*S. feltiae* 106/l) injected	83	54	79	119

In another set of experiments, the efficacy of injected nematodes was compared with injected insecticide, and the nematodes applied as a spray. It was clear that nematodes sprayed onto the branch surface killed fewer borer larvae than when injected into a gallery (Table 37.1). The injection of a suspension of nematodes into borer galleries resulted in higher mortality than an injection of an insecticide, acephate (Table 37.1).

In subsequent trials, special care was taken to ensure optimum weather conditions for nematode spray applications. Trees infested with *O. hirta* larvae were sprayed on warm, overcast days during drizzling rain. Larvae were recovered after 14 days and corpses were examined to see if the nematode applied could be isolated (Table 37.2). The efficacy of the nematode application depended on the numbers applied. Mortality due to the nematode did not exceed 34%. Comparison with controls suggested that this mortality was in addition to other factors. Results were no better in an experimental vineyard nor did we observe any indication of greater efficacy from *Heterorhabditis heliothidis*.

Table 37.2 Mortalities due to spray application (5×10^2N/ml – 5×10^4N/ml) of either *Steinernema bibionis* or *Heterorhabditis heliothidis* to citrus trees (mixed varieties) or grape vines (cv. Cabernet Sauvignon). Mortality due to ichneumonid parasitism or ant predation are listed for comparison. Experiments were carried out in the Auckland area with application dates as follows: (1) 22-31 December 1981 (2) 15 February 1983 (3 & 4) 9 May 1984. All were harvested 2 weeks later.

Nematode species	Concentrations N/ml	No. borer larvae	Cause of mortality (%)				
			Nematodes	*X. novo-zelandicus*	Ants	Undefined	Total
(1) *CITRUS* SP.,	PUKETUTU ISLAND						
–	0	62	0	16	2	27	45
S. bibionis	5×10^2	122	7	13	1	23	44
„	5×10^3	104	25	13	3	23	64
„	5×10^4	71	34	11	4	28	77
(2) *CITRUS* SP.,	PUKETUTU ISLAND						
–	0	49	0	8	0	2	10
S. bibionis	5×10^2	49	4	10	0	35	49
„	5×10^3	49	22	4	0	12	38
(3) GRAPES, HUAPAI							
–	0	9	0	0	0	0	0
S. bibionis	5×10^2	7	0	0	0	0	0
„	5×10^3	12	17	0	0	0	17
„	5×10^4	17	6	0	0	6	12
(4) GRAPES, HUAPAI							
Heterorhabditis sp.	5×10^2	11	0	0	0	18	18
„	5×10^3	13	0	0	0	0	0
„	5×10^4	10	20	0	0	10	30

Evaluation

Dye's (1950) conclusion that *X. novozelandicus* is inadequate to control *O. hirta* appears valid. Spray inoculation of nematodes reduces borer numbers, but it is doubtful if the benefits would be sufficient to compensate for the care and forethought that would be required of a horticulturalist in choosing a suitably moist day for spraying.

Conclusions

O. hirta remains a very difficult insect to control. The protected niche of the larvae and low natural levels of parasitism result in a pest that is frequently damaging, and occasionally causes severe yield reductions in citrus orchards. Wound-dressings containing insecticide and nematode applications do not appear likely to be economically useful control measures.

Acknowledgements

This chapter describes unpublished experiments carried out in collaboration with W.M. Wouts and M. Surrey, Nematology Group, S.J. Muggleston and K.L. Wildish, Horticulture Group, and J.S.Dugdale, Systematics Group, all of Entomology Division, DSIR. K.L. Wildish was recipient of the 1981/82 Fruitgrowers Federation Bursary.

Literature Cited

Clearwater, J.R. (1981) Lemon tree borer, *Oemona hirta* (Fabricius), life cycle. *DSIR information series*, 105/33.

Clearwater, J.R.; Muggleston, S.J. (1985) Protection of pruning wounds: favoured oviposition sites for the lemon tree borer. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 199-202.

Clearwater, J.R.; Wouts W.M. (1980) Preliminary trials on the control of lemon tree borer with nematodes. *Proceedings of the 33rd New Zealand Weed and Pest Control Conference*, 133-135.

Dumbleton, L.J. (1937) Borers in fruit trees. *New Zealand journal of agriculture*, 295-298.

Dye, M.H. (1950) Studies on the anatomy and biology of *Oemona hirta* Fabricius (Coleoptera: Cerambycidae). M.Sc. thesis, Auckland University, New Zealand, 106 pp.

Gourlay, E.S. (1930) Preliminary host list of the entomophagous insects in New Zealand. *DSIR bulletin* 22, 1-13.

Kaya, H.K.; Hotchkin, P.G. (1981) The nematode *Neoaplectana carpocapsae* Weiser and its effect on selected ichneumonid and braconid parasites. *Environmental entomology* 10, 474-478.

Linsley, E.G. (1959) Ecology of Cerambycidae. *Annual review of entomology* 4, 99-137.

Spiller, D.M.; Wise K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR bulletin* 231, 260 pp.

Panonychus ulmi (Koch), European red mite (Acari: Tetranychidae)

J.T.S. WALKER, C.H. WEARING and A.J. HAYES

Pest Status

The European red mite, *Panonychus ulmi* (Koch), is a cosmopolitan pest of pome and stone fruits. In New Zealand *P. ulmi* is commonly found on apple, pear (*Pyrus communis* L. and *P. pyrifolia* (Burman) Nakai) and apricots, and is frequently a serious pest of these crops. It also occurs on peaches, plums, nectarines and cherries, but serious infestations on these crops are usually less common. It may also be found on almond, walnut, grape, currant, gooseberry, raspberry, elm, oak, mountain ash and on ornamental trees and shrubs of the genera *Prunus*, *Sorbus* and *Ribes* (Collyer 1984). In New Zealand, *Panonychus ulmi* overwinters as eggs on the bark of host plants. Hatching of eggs commences in late September and continues until early November. Hatching larvae are six-legged while all subsequent stages are eight-legged. There are five to six summer generations, the first two generations being distinct but there is increasing overlap with subsequent generations. *P. ulmi* feeds mainly on the lower surface of leaves, by inserting its stylets through the epidermis and sucking the contents of inner leaf cells. Most crops attacked can tolerate feeding damage by low populations of *P. ulmi*, but when high numbers of mites are present, serious leaf bronzing or defoliation may occur. Once leaf condition deteriorates in the presence of high mite numbers, mites may hang from leaves on silken threads and dipserse, reducing mite numbers on heavily infested trees (Collyer 1976).

The European red mite was formerly known as *Paratetranychus pilosus* Canestrini & Fanzago then *Metatetranychus ulmi* (Koch) and later as *Panonoychus ulmi*. Cottier (1934a) reported use of the common name, red mite, to describe two mite species *P. ulmi* and *Bryobia praetiosa* Koch. This may have resulted in some confusion in early reports of mite damage. Prior to the introduction of modern synthetic pesticides in the late 1940s, reports of *P. ulmi* damage to tree fruits were received by DSIR (DSIR files). These mostly mentioned control problems for which the primary recommendation was the application of oil sprays (Cottier 1935). In 1951 red mite outbreaks were reported where DDT was used for the control of codling moth, *Cydia pomonella* (L.) (Taylor 1951). In a national survey of orchards, Lamb (1958) reported that *P. ulmi* was the dominant pest mite species and that natural enemies were less abundant in heavily sprayed orchards. Collyer (1964) reported that the use of DDT in New Zealand orchards had increased the phytophagous mite problem and that frequent applications of acaricides were necessary for the control of *P. ulmi*. She also reported that *P. ulmi* was resistant to organophosphorus acaricides in major fruit growing districts.

Background

Cottier (1934b) reviewed and described four species of natural enemies of *P. ulmi* in New Zealand. These were; two insect predators, described as *Scymnus* sp. (Coccinellidae) and *Arthrocnodax* sp. (Cecidomyiidae), and two mite predators, described as a gamasid mite of the super-family Parasitoidea and a mite of the super-family Trombidoidea. These natural enemies were probably among those described later by Collyer (1964, 1976). Miller *et al.* (1936), in their review of biological control of insects and weeds in New Zealand, did not consider red mite a likely candidate for biological control. Consequently, there are no

reported attempts to introduce any biological control agents for *P. ulmi* prior to 1965. With increasing mite control problems in commercial apple orchards, associated with the use of broad spectrum pesticides such as DDT, Collyer completed more detailed studies on natural enemies of *P. ulmi* present in New Zealand (Collyer 1964, 1976). These studies listed insect predators of the families Coccinellidae, Miridae, Cecidomyiidae, Anthocoridae and Thripidae. Mite predators included members of the families Phytoseiidae and Stigmaeidae (Collyer 1964, 1976).

Stethorus bifidus Kapur was recognised by Collyer (1964, 1976) as the most common insect predator of *P. ulmi* in New Zealand orchards, capable of decreasing mite numbers on apple trees, but only after insecticide spraying ceased. Elsewhere, this genus has been recognised as containing important predators of *P. ulmi* (McMurtry *et al.* 1970). The mirid, *Sejanus* (= *Idatiella*) *albisignata* (Knight), has also been recorded feeding on *P. ulmi* on apple (Collyer 1964, 1976) but it also was adversely affected by conventional pesticide programmes. Larvae of *Arthrocnodax* sp. (Cecidomyiidae) have been recorded feeding on mites, usually two-spotted mite, (*Tetranychus urticae* Koch), on weeds and trees in late summer (Collyer 1964, 1976). The anthocorid, *Cardiastethus* sp., has also been reported to feed on *P. ulmi* (Collyer 1964) and a thysanopteran, *Apterygothrips collyerae* Mound & Walker, first mentioned by Collyer (1976) as *Xylaplothrips* sp. nr. *fuliginosus*, was noted as a predator of *P. ulmi* eggs (Collyer 1976). Another thysanopteran, *Haplothrips kurdjumovi* Karny, which is known to prey on *P. ulmi* in North American orchards under the synonym of *H. faurei* Hood (MacPhee 1953, Putman 1965), has been found in Central Otago in association with *P. ulmi* winter eggs on apricots and is suspected to feed on them (G.F. McLaren pers. comm.).

In New Zealand the most important mite predator of *P. ulmi* is *Typhlodromus pyri* Scheuten (Phytoseiidae). It was probably accidentally introduced into New Zealand with early European settlement and is common in most orchard areas (Collyer 1982). It is resistant to many orchard pesticides (Wearing & Ashley 1982) and has been used successfully in an integrated programme for the control of *P. ulmi*. Integrated mite control, based on *T. pyri*, is now a recognized management practice on commercial orchards (Wearing *et al.* 1978). Although many endemic species are listed in Collyer's (1982) review of New Zealand Phytoseiidae, only *Neoseiulus cucumeris* (Oudemans) is listed as a predator of *P. ulmi*. Collyer (1964) considered *Agistemus longisetus* Gonzalez (Stigmaeidae) a potentially important predator of *P. ulmi*. She reported that it reproduced rapidly and was apparently tolerant of some orchard pesticides.

Importations, Releases and Recoveries

Predatory insects

Predatory insects were introduced for the control of *P. ulmi* and *Tetranychus urticae* on tree crops. It was thought that once established they might also be effective predators of aphids and possibly feed on codling moth eggs. The mirid, *Blepharidopterus angulatus* (Fallén), was introduced from England in 1966 (Cameron *et al.* 1987) and was released on apple trees at two sites in Nelson. A total of 107 females and 120 males was released. Small numbers of nymphs were recovered for several years but no further recoveries were made after removal of the release trees (DSIR files). Another mirid, *Hyaliodes harti* Knight, was imported from Nova Scotia, Canada, in 1966. Fifty females and 83 males were released on to caged trees. Eggs were laid but nymphs did not hatch in 1967 (DSIR files). Failure to establish was attributed to relatively high winter temperatures.

Two members of the family Anthocoridae were also introduced, *Anthocoris nemorum* (L.) from the East Malling Research Station (Kent, England) between 1965-67, and *A. musculus* (Say) from Nova Scotia, Canada in 1965-66. Five consignments of *A. nemorum* were received during 1965-66 and a further three in 1966-67. A total of 1,000-2,000 were released at two sites in the Nelson district but no recoveries were made in the following

season (DSIR files). Failure to establish was also attributed to relatively high winter temperatures. Two consignments of *A. musculus* were received and from these a total of 400 individuals was released at two sites in the Nelson district (DSIR files). There is no report on the status of *A. musculus* at these release sites but it is assumed that this predator did not become established.

Predatory mites

Three species of predatory mites have been introduced for the control of phytophagous mites.

Phytoseiulus persimilis Athias-Henriot (Acari: Phytoseiidae)

Phytoseiulus persimilis was first introduced from Britain in 1967 for the control of *T. urticae* (Chapter 42). This initial release did not establish successfully (Walker *et al.* 1981). In 1977 further material was introduced from the south of France and in 1978 releases were made into unsprayed areas surrounding horticultural crops in Auckland, Waikato, Hawke's Bay and Nelson. This strain rapidly became established and widespread (Walker *et al.* 1981). Although introduced for the control of *T. urticae*, *P. persimilis* was frequently found feeding on *Panonychus ulmi* where mixed populations of these phytophagous mites were present on apple. With the successful establishment of *Phytosiulus persimilis* the pest status of *T. urticae* in commercial orchards has declined significantly and consequently, it is now uncommon to find *P. persimilis* present in fruit trees or feeding upon *Panonychus ulmi*. Further information on the release and establishment of this predator is given in Chapter 42.

Neoseiulus (= *Amblyseius*) *fallacis* (Garman) (Acari: Phytoseiidae)

Neoseiulus fallacis was introduced from Michigan, U.S.A. as *Amblyseius fallacis* in 1972, 1973 and 1975. Although the 1972 consignment failed, later consignments were successful and frequent releases were made on to apple trees infested with *P. ulmi* at the Appleby Research Orchard between 1973 and 1976 (Chapter 42). Despite a regular release programme and a high release rate (100-200 predators per tree) *A. fallacis* failed to become established at this location (Thomas & Chapman 1978). Releases of *N. fallacis* were also made in Canterbury where it was established successfully and controlled mites on trees with mixed populations of *P. ulmi* and *T. urticae*. Subsequent trials in Canterbury and Blenheim indicated that *N. fallacis* numbers were most closely correlated with *T. urticae* populations in late summer. This predator contributed little to the control of *P. ulmi* in early summer and acaricidal treatments would probably still be required for the control of this species (Thomas & Chapman 1978). Further information on the release and establishment of this predator is given in Chapter 42.

Metaseiulus (= *Typhlodromus*) *occidentalis* Nesbitt (Acari: Phytoseiidae)

Metaseiulus occidentalis was introduced from Australia (as *Typhlodromus occidentalis*) for the control of *T. urticae* in 1976 (Chapter 42). Releases were made in commercial orchards in Nelson, Hawke's Bay, Waimate, Loburn and Lincoln (Thomas & Chapman 1978). This predator increased dramatically at the Nelson release site where *T. urticae* was present and was observed feeding on *P. ulmi*. In the following seasons it declined to low densities when *T. urticae* was less abundant.

Evaluation

Insect predators of *P. ulmi* were introduced into orchards in the hope that they might become established and control both mite and aphid pests. While *B. angulatus* was recovered for

several seasons at the release sites neither it, nor the other introduced predators, were established successfully. These failures were probably due to the relatively mild winter temperatures in New Zealand compared to those at the source locations of the predators.

Predatory phytoseiid mites were introduced into New Zealand primarily for the control of *Tetranychus urticae*, and only to augment control of *Panonychus ulmi* by *Typhlodromus pyri*. The release programme for all three phytoseiids has contributed little to the control of *P. ulmi*. However, the successful establishment of *Phytoseiulus persimilis* for control of *Tetranychus urticae* has effectively complemented the existing programme for control of *Panonychus ulmi* by *Typhlodromus pyri*.

Conclusions

There is no requirement for specific importations to assist with the biological control of *P. ulmi*. This pest species is effectively regulated at low levels by *T. pyri* in commercial orchards, provided adequate care is taken to avoid pesticides which are toxic to the predator and therefore disruptive to integrated mite control. In unsprayed habitats this phytoseiid predator is assisted by a range of insect predators to maintain *P. ulmi* at very low levels which do not damage the crop.

Literature Cited

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242. 51 pp.

Collyer, E. (1964) Phytophagous mites and their predators in New Zealand orchards. *New Zealand journal of agricultural research* 7, 551-568.

Collyer, E. (1976) Integrated control of apple pests in New Zealand. 6. Incidence of European red mite, *Panonychus ulmi* (Koch), and its predators. *New Zealand journal of zoology* 3, 39-50.

Collyer, E. (1982) The Phytoseiidae of New Zealand (Acarina) 1. The genera *Typhlodromus* and *Amblyseius* – keys and new species. *New Zealand journal of zoology* 9, 185-206.

Collyer, E. (1984) European red mite, *Panonychus ulmi* (Koch), life cycle. *DSIR information series* 105/5.

Collyer, E.; Geldermalsen, M. van (1975) Integrated control of apple pests in New Zealand I. Outline of experiment and general results. *New Zealand journal of zoology* 2, 101-134.

Cottier W. (1934a) The European red-mite in New Zealand (*Paratetranychus pilosus* Can. & Fanz.). *New Zealand journal of science and technology* 16, 39-56.

Cottier W. (1934b) The natural enemies of the European red-mite in New Zealand (*Paratetranychus pilosus* Can. & Fanz.). *New Zealand journal of science and technology* 16, 68-80.

Cottier W. (1935) Red-mite control by oil sprays. *New Zealand journal of science and technology* 16, 261-270.

DSIR, Entomology Division, file BC 1/4.

Lamb K.P. (1958) Red spider mite survey on apples, 1957-58. *The orchardist of New Zealand* 31, 311-313.

MacPhee A.W. (1953) The influence of spray programs on the fauna of apple orchards in Nova Scotia. V. The predaceous thrips *Haplothrips faurei* Hood. *Canadian entomologist* 85, 33-40.

McMurtry, J.A.; Huffaker, C.B.; Vrie, M. van. (1970) Ecology of tetranychid mites and their natural enemies. I. Tetranychid enemies: their biological characters and the impact of spray practices. *Hilgardia* 40, 331-390.

Miller, D.; Clark, A.F.; Dumbleton, L.J. (1936) Biological control of noxious insects and weeds in New Zealand. *New Zealand journal of science and technology* 18, 579-593.

Putman, W.L. (1965) The predaceous thrips *Haplothrips faurei* Hood (Thysanoptera: Phloethripidae) in Ontario peach orchards. *Canadian Entomologist* 97, 1208-1221.

Taylor, G.G. (1951) Spray treatments with DDT for control of codling moth (*Cydia pomonella* L.) in apple orchards. *New Zealand journal of science and technology* 33, 60-65.

Thomas, W.P.; Chapman, L.M. (1978) Integrated control of apple pests in New Zealand. 15. Introduction of two predacious phytoseiid mites. *Proceedings of the 31st New Zealand Weed and Pest Control Conference*, 236-243.

Walker, J.T.S.; Wearing, C.H.; Proffit, C.; Charles, J.G. (1981) Predator for two-spotted spider mite establishes in orchards. *The orchardist of New Zealand* 54, 340.

Wearing, C.H.; Ashley, E. (1982) A recommended spray programme for integrated mite control on apples. *The orchardist of New Zealand* 55, 27-29.

Wearing, C.H.; Collyer, E.; Thomas, W.P.; Cook, C. (1978) Integrated control of apple pests in New Zealand. 12. Commercial implementation of integrated control of European red mite in Nelson. *Proceedings of the 31st New Zealand Weed and Pest Control Conference*, 214-220.

Pseudococcidae, mealybugs (Homoptera)

J.G. CHARLES

Pest Status

Most of the 116 species of mealybugs known from New Zealand are indigenous, but nine are more or less cosmopolitan and are pests in Europe and North America (Cox 1987). Three of these, *Pseudococcus longispinus* (Targioni-Tozzetti), *P. calceolariae* (Maskell) and *P. affinis* (Maskell), are major pests on a wide range of horticultural crops in New Zealand. Williams (1985) presumed that they originated in Australia, but Cox (1987) considered *P. affinis* to be almost certainly a North American native. The biology of these mealybugs in New Zealand has been poorly studied, partly because of confusion as to their identity. Miller (1934) summarised early knowledge of mealybug biology, while Charles (1981, 1982a, 1982b) and Charles & Walker (1981) discussed aspects of the biology, ecology and control of *P. longispinus* and *P. affinis* on grapes and apples. Mealybugs (*P. longispinus*) were first considered to be pests on grapevines under glass in the 1890s (Broun 1896). *P. longispinus*, *P. calceolariae* and *P. affinis* can now be found throughout New Zealand. They have an extremely wide host range and together may be considered as potential pests on most commercial horticultural crops grown in New Zealand. Regional effects (mostly climatic), together with different crop and management practices, may combine to influence significantly the species composition at any one location. For example, Cox (1977a) and Charles (1981) found only *P. longispinus* in Auckland vineyards, whereas Ward (1966) found only *P. affinis* in Hawke's Bay vineyards. Charles (unpublished data) found only a few *P. longispinus* in a Gisborne vineyard, where nearly all mealybugs were *P. calceolariae*. *P. affinis* is usually found arboreally in New Zealand, but in Australia it is also regarded as the most important of the underground mealybug pests (Williams 1985).

In addition to these three cosmopolitan and major pest species, there are a few minor pest mealybugs. *Phenacoccus graminicola* Leonardi is a grass feeding species (originally described from Italy but found elsewhere in Europe, in the U.S.A., and in South Africa), and an intermittent pest of fruit trees in Hawke's Bay and Nelson if tall grass is allowed to grow too close to fruit trees (Collyer & van Geldermalsen 1975, Cox 1977a, Ward 1966). *Planococcus mali* Ezzat & McConnell is known from native hosts, but is also of economic significance on blackcurrants. Heavily infested plants may suffer from bud deterioration over the winter months. *P. mali* is also known from Tasmania, but its origin is uncertain (Williams 1985). *Balanococcus poae* (Maskell) is a root-feeding mealybug, frequently found in pasture throughout New Zealand, which may be damaging when plants are under drought-stress (W.D. Pearson pers. comm.). *Balanococcus diminutus* (Leonardi), the New Zealand flax mealybug, may be very common on New Zealand flax, *Phormium tenax* J.R. & G. Forster and can kill young plants in nurseries. *B. diminutus* is probably a native species which has been distributed around the world on ornamental *P. tenax* plants. *Rhizoecus falcifer* Künckel d'Herculais, a root pest of many greenhouse crops in Europe and North America is relatively common in New Zealand (Cox 1987). *Planococcus citri* (Risso), an important pest of citrus overseas, is intercepted frequently at New Zealand ports, but although there have been isolated records on greenhouse crops and indoor plants, it has not become an established pest (Emms 1981).

Pseudococcus comstocki and *P. maritimus* do not occur in New Zealand. All past records in this country are either misidentifications, or quotes from previous sources (Cox 1977b).

Mealybugs can be difficult to identify. The three major pest species have been present in horticultural crops in New Zealand for nearly 100 years, and have been recorded in the literature under a variety of names. Advances in taxonomy and detailed study of New Zealand specimens have enabled appropriate synonymies to be made (Cox 1977b, 1987, Miller *et al.* 1984, Williams & de Boer 1973) (Table 39.1).

Table 39.1 Current names of pest mealybugs found in New Zealand, their literature names and common names.

Current name	Literature names	Common name
Pseudococcus affinis (Maskell)		Obscure mealybug
	= *P. obscurus* Essig	Obscure mealybug
	= *P. maritimus* (Ehrhorn)	Baker's mealybug
P. calceolariae (Maskell)		Citrophilus mealybug
	= *P. citrophilus* Clausen	Citrophilus mealybug
	= *P. fragilus* Brain	
	= *P. gahani* Green	
	= *P. comstocki* (Kuwana)	Comstock's mealybug (Apple mealybug)
	= *P. maritimus* (Ehrhorn)	Baker's mealybug (Apple mealybug)
P. longispinus (Targioni-Tozzetti)		Longtailed mealybug
	= *Dactylopius adonidum* auct.	
	= *Pseudococcus adonidum* auct.	
Phenacoccus graminicola Leonardi		Grass mealybug
	= *P. graminosus* McKenzie	
Balanococcus diminutus (Leonardi)		New Zealand flax mealybug
	= *Trionymus diminutus* (Leonardi)	
B. poae (Maskell)		Pasture mealybug
	= *Pseudantonina poae* (Maskell)	

Although high numbers of mealybugs may seriously debilitate their hosts, modern chemical sprays applied against them or against other pests usually prevent such massive outbreaks. Nevertheless, even low numbers can cause fruit to be downgraded because of sooty mould. Mealybugs remain a quarantine problem on many export crops because their cryptic nature makes them difficult to detect and reject while picking, grading or packing. Mealybugs are the major pest on the new export crop of persimmons (Sale & Steven 1985).

Background

Mealybugs are extremely difficult to control with pesticides because of their cryptic behaviour, preferring to live in deep cracks, crevices and other hiding places. Spray penetration becomes difficult, and although soft-bodied, the wax that all mealybugs secrete forms a barrier between aqueous pesticide solutions and the cuticle. Mature adult females and egg-sacs are particularly well protected by a network of wax filaments. Historically, attempts to control mealybugs have often been dangerous – involving cyanide fumigation or nicotine sulphate sprays – and not particularly effective. Rotenone and derris dust in laboratory and field trials showed promising results (Atkinson 1940). After 1945, DDT provided reasonable control for a time, but reported resistance (Congdon & Morrison 1959) led to a change to organophosphate

insecticides. Mealybugs have continued to be a recurring problem on a range of crops since then, although recent trials have led to improvements in the timing of pesticide applications (Charles 1982a, Charles & Walker 1981).

Early success with the biological control of insects prompted considerable efforts to use natural enemies in New Zealand for the control of mealybugs, especially from 1896 to 1933 when 14 species of parasitoids and predators were deliberately imported into New Zealand from Australia and the U.S.A.

As well as these planned introductions, a number of species which are considered to be of importance overseas have also become established, either accidentally or as natural immigrants. There is also a poorly studied natural enemy fauna of the native mealybugs, some of which have been recorded from pest mealybugs. These species (with selective synonymy) are listed here.

Parasitoids
Hymenoptera: Encyrtidae

Tetracnemoidea brevicornis (Girault)

= *Tetracnemus pretiosus* Timberlake (1929)
= *Hungariella ?pretiosa* (Timberlake) (in Valentine 1967; 1123)

Tetracnemoidea brevicornis is widespread from Auckland to Southland (Noyes 1988). The species was originally collected from Sydney, then released in the U.S.A. for mealybug control (Smith & Compere 1928). Specimens were brought into New Zealand as *Tetracnemus* sp. in 1927 and 1928, but they did not survive and were not released (DSIR files). It is not known when *Tetracnemoidea brevicornis* became established in New Zealand. It has been recorded from *Pseudococcus* sp. and *Phenacoccus graminicola* and reared from unidentified mealybugs on ngaio (*Myoporum laeta* Cheeseman) (Noyes 1988), but not specifically from *Pseudococcus calceolariae*, a pest which it controls well in California.

Tetracnemoidea brounii (Timberlake)

= *Tetracnemus brounii* Howard (MS) nomen nudum (in Broun 1898; 219)
= *Tetracnemus brounii* Timberlake 1929
= *Hungariella brounii* (Timberlake) (in Valentine 1967; 1123)

Broun (1898) discovered this encyrtid feeding on *P. longispinus*, and considered it to be a valuable mealybug predator. Broun sent specimens to L.O. Howard (United States Department of Agriculture) who gave it the manuscript name *Tetracnemus brounii*. No description was published, but Timberlake (1929) gave the MS name to specimens received from E.S. Gourlay. He indicated the characters of *T. brounii* which separated it from the closely related Australian species, *Tetracnemoidea brevicornis*. Gourlay (1930) incorrectly reported that Timberlake (1929) had indicated the characters of *Ophelosia 'dactylopii'*, a pteromalid species discovered by Broun at the same time. Timberlake in this paper only discussed *Tetracnemus*, not *Ophelosia 'dactylopii'*. Subsequent records have shown *Tetracnemoidea brounii* to be widespread throughout New Zealand in habitats ranging from native *Nothofagus* spp. and podocarp forest through regenerating scrub and tussock to domestic and commercial gardens (Noyes 1988). It has been recorded from *P. calceolariae*, but most of the known host records are of unidentified mealybugs collected from native plants (Noyes 1988).

Tetracnemoidea peregrina (Compere)

= *Hungariella peregrina* (Compere) (in Valentine 1967; 1123)

This species is self introduced, and is considered to be quite common in Auckland (Valentine pers. comm.). However, Noyes (1988) was unable to confirm its existence in New Zealand because of the poor condition of the preserved specimens available. *T. peregrina* is principally a parasitoid of *P. longispinus*, but can also reproduce on *P. calceolariae* and

possibly *P. affinis* (Bartlett 1978). Its origin is uncertain, but is probably either South America or southern Africa. It is doubtfully present in Australia, but is known from the U.S.A., Italy and France (Noyes 1988).

Tetracnemoidea sydneyensis (Timberlake)

= *Anarhopus sydneyensis* Timberlake (1929)

T. sydneyensis was described from Sydney, Australia and introduced to California in 1933 (Compere & Flanders 1934). The species has never been released in New Zealand, but was recorded by Valentine (1963). It must be considered a recent and accidental introduction.

Tetracnemoidea zelandica Noyes

T. zelandica is native to New Zealand and occurs in both the North and South Islands in a variety of habitats. It has been reared from *Planococcus mali* on blackcurrant, and from an unidentified mealybug on gorse (Noyes 1988). *P. mali* may be commonly parasitised in the South Island (W.P. Thomas pers. comm.). Nothing further is known of its biology.

Gyranusoidea advena Beardsley

All species of this cosmopolitan genus are parasitoids of Pseudococcidae. *G. advena*, native to Hawaii, is only known in New Zealand from two females (misidentified as *Anagyrus* sp. by Valentine (1963)), reared from *Pseudococcus* sp. on lemon from Tauranga (Noyes 1988). It has probably been accidentally introduced to New Zealand quite recently.

Alamella mira Noyes

All three species of this genus parasitise Pseudococcidae. *A. mira* is known only from Auckland, New Zealand, where it has been reared from *P. longispinus* on citrus (Noyes 1988).

Odiaglyptus biformis Noyes

O. biformis has been reared from *Balanococcus poae* on pasture grass. Another seven species of encyrtids have also been reared from pseudococcids in New Zealand: *Adelencyrtoides unicolor* Noyes, *Rhopus anceps* Noyes, *Rhopus* sp. A, *Subprionomitus ferus* (Girault), *Tetracnemoidea bicolor* (Girault), *Tongyus costalis* Noyes and *Tongyus regis* Noyes (Noyes 1988).

The biology of many of the 67 species of Encyrtidae now recorded from New Zealand is unknown (Noyes 1988). Cox (1987) estimates that, in New Zealand, there may be more than double the 116 species of Pseudococcidae so far described. Given the close relationship that exists between species of the two groups, it is likely that many encyrtid parasitoids of Pseudococcidae in New Zealand remain to be discovered. However, most of these are also likely to be restricted to specialised habitats and have no impact on the pest mealybugs. Indeed, after 100 years of colonisation by the three major pest species, any native encyrtid with the capacity to exert significant control on the populations of the pests would already have done so.

Encyrtidae are nevertheless valuable natural enemies. Clausen (1978) listed 97 programmes worldwide in which encyrtids played a major role in biological control, especially of Coccidae and Pseudococcidae. Despite their recognised significance internationally, there has been no attempt to evaluate their potential role in the control of mealybug pests in New Zealand.

Hymenoptera: Pteromalidae

Ophelosia 'dactylopii' nomen nudum (in Broun 1898; 219)

Ophelosia spp. (in Valentine 1967; 1129)

Most species of this genus for which any biology is known are predators within the ovisacs of pseudococcids. They may also be hyperparasitic on primary internal parasitoids of

mealybugs and so may be unsuitable candidates for classical biological control programmes (Compere & Flanders 1934). *Ophelosia* sp. was first recorded in New Zealand by Broun (1898) and considered by him to be a potentially valuable natural enemy of *P. longispinus*. Named *O. dactylopii* in manuscript by Howard, the specimens have subsequently been lost (Valentine 1967). Valentine (1967) also records possibly five more species from New Zealand which have been reared from pseudococcid ovisacs. Charles (unpublished data) has collected *Ophelosia* sp. (determined by Z. Bouček) from ovisacs (and also groups of male cocoons) of *P. affinis* and *P. calceolariae* from apple trees and grapevines in Hawke's Bay and Gisborne. There are commonly three or four *Ophelosia* larvae in an ovisac, but there have been no studies of their impact on population development of the mealybugs.

Hymenoptera: Aphelinidae

Coccophagus spp.

There are at least four undescribed native species of *Coccophagus* which are parasitic on native pseudococcid species (Valentine 1963).

Predators

Neuroptera: Coniopterygidae

Cryptoscenea australiensis (Enderlein)

Kimmins & Wise (1962) recorded the discovery in New Zealand of this neuropteran, a species previously known only from Australia. They found *C. australiensis* feeding on pseudococcids of the genus *Balanococcus* (as *Trionymus*) in Auckland, but also received a specimen from E.S. Gourlay that had been collected from mealybugs in Nelson in 1927. Collyer & van Geldermalsen (1975) also found *C. australiensis* feeding on mealybugs on apple trees in Nelson, and Charles (1981) recorded it in Auckland vineyards and noted its ability to destroy a laboratory colony of *P. longispinus*. Charles (unpublished data 1982-1983) has also recorded *C. australiensis* from Hawke's Bay, feeding on *P. longispinus*, *P. calceolariae* and *P. affinis* on apple trees. From these records, it appears that *C. australiensis* is widespread throughout New Zealand, at least from Nelson northwards, and that it arrived as an accidental introduction from Australia at least 60 years ago. Individual adults and larvae are voracious predators of mealybugs and further study of their ability to regulate mealybug populations would be worthwhile.

Neuroptera: Hemerobiidae

Micromus tasmaniae (Walker)

M. tasmaniae is listed by Miller (1945) as a natural enemy of mealybugs, but I can find no recorded observations of this generalist predator feeding on them in New Zealand. However, Furness (1976) found *M. tasmaniae* feeding on *P. longispinus* in South Australia, and other hemerobiids (*Sympherobius* spp.) may be important predators of high populations of mealybugs in California (Bartlett & Lloyd 1958).

Diptera: Syrphidae

Melanostoma fasciatum (Macquart)

M. fasciatum is probably a native species and is common throughout New Zealand in modified habitats (B.A. Holloway pers.comm.). Charles (1981) recorded that the larvae of *M. fasciatum* were voracious predators of *P. longispinus* in Auckland vineyards after January, when the mealybug population began to increase with the second generation. Up to 30 dead adult and third instar mealybugs were found in association with one *M. fasciatum* larva. The syrphid larvae were, however, very susceptible to insecticides applied for mealybug control.

Diptera: Cecidomyiidae *Diadiplosis koebelei* (Koebele)

The predatory larvae of this species are common in mealybug colonies in Auckland vineyards (Charles 1981), but they are probably not restricted to Auckland. Although *D. koebelei* was imported into New Zealand in 1927 and 1928 as *Diplosis* sp. it was not released, and has probably become established from accidental imports on mealybug infested produce (Charles 1985).

Coleoptera: Coccinellidae

Scymnus loewi Mulsant

S. loewi is a North and Central American native (Gordon 1985). It is an accidental immigrant to New Zealand where it was first recorded from Auckland in 1941 (New Zealand Arthropod Collection). Charles (1981) found larvae and adults feeding on *P. longispinus* under the bark of grapevines in Auckland, and on *P. affinis* and *P. calceolariae* on apple trees in Hawke's Bay (unpublished data). Larvae appear very similar to mealybugs, and are covered with a dense, white, waxy secretion, similar to that of *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae).

Importations, Releases and Recoveries

Deliberate importations of natural enemies for mealybug control were made from 1897 to 1933. Two periods can be identified. From 1897 to 1924, biological control efforts centred on the introduction and establishment of *Cryptolaemus montrouzieri*. From 1927 to 1933 efforts were directed towards the establishment of the then recently discovered Australian parasitoid, *Coccophagus gurneyi* Compere (Hymenoptera: Aphelinidae). In the intervening period, from 1924 to 1926, a number of mealybug natural enemies of Australian and Californian origin were also imported, but these were not released.

Cryptolaemus montrouzieri Mulsant (Coleoptera: Coccinellidae)

C. montrouzieri, an Australian native, was introduced into California by Koebele in 1892, and by 1896 had become well known as a voracious and effective predator of mealybugs. Following recommendations in 1896 for its introduction into New Zealand, two consignments were sent from Australia in 1897 (Table 39.2). The first, from the New South Wales Department of Agriculture, arrived in New Zealand on 6 January 1897 (Kirk 1897, Broun 1897). Liberations were made in Whangarei, Auckland and Wellington, but there were no recoveries. A subsequent report suggested that they were not 'the right species' (New Zealand Farmer September 1897). The second consignment was collected by the New Zealand Government Biologist, T.W. Kirk, during a trip to Brisbane, and arrived at Whangarei on 17 July 1897. Although the specimens were definitely *C. montrouzieri*, only 19 out of 200 survived the journey (because of lack of a food supply) (Northern Advocate 31 July 1897). All 19 beetles were transferred to an insectary in Whangarei for breeding, but no eggs were laid and the colony died out (Weekly News 27 November 1897). At about this time, a Whangarei grape grower and amateur entomologist, A.T. Potter, privately imported a consignment of *C. montrouzieri* eggs from Australia (Auckland Star 18 April 1898, Herald Weekly 16 April 1898, Northern Advocate 22 January 1898). About 150 larvae emerged from these eggs, and from these he established a thriving colony. T. Broun confirmed the identity of the beetles and the colony was purchased by the Department of Agriculture in March 1898 (Northern Advocate 19 March 1898). The ladybirds then became freely available

Table 39.2 Consignments of *Cryptolaemus montrouzieri* to New Zealand, 1897-1924. * = Releases made directly from these consignments, or colonies started from which subsequent releases were made.

Date		Country of origin	Released	Reference
6 January	1897	Australia, N.S.W.	yes	Broun 1897, Kirk 1897
17 July	1897	Australia, Qld.	no	Northern Advocate (DSIR files)
summer	1897	Australia	yes*	Northern Advocate (DSIR files)
1 November	1921	Australia, N.S.W.	yes	Northern Advocate (DSIR files)
16 December	1922	Australia, N.S.W.	no	Northern Advocate (DSIR files)
28 August	1923	U.S.A., Ca.	yes*	DSIR files
15 November	1923	Australia, N.S.W.	yes*	DSIR files
18 February	1924	U.S.A., Ca.	yes	DSIR files
19 November	1924	Australia, N.S.W.	yes	DSIR files
26 November	1925	U.S.A., Ca.	no	DSIR files
9 December	1925	Australia N.S.W.	?	DSIR files
18 December	1926	U.S.A., Ca.	no	DSIR files

N.S.W. = New South Wales, Qld. = Queensland, Ca. = California

and were reared and widely distributed throughout New Zealand during 1898-1901 (Potter 1899, 1900, 1901). The predators were initially very successful against mealybug and also against *Eriococcus coriaceus* Maskell (Homoptera: Eriococcidae) on Norfolk pines, but by 1909 it was considered that they could not survive in the cooler parts of New Zealand (Kirk & Cockayne 1909). By 1920 *C. montrouzieri* had become uncommon in the North Island, and because *P. affinis* became a problem on apples in that year, further consignments of *C. montrouzieri* were sent from Australia and California. A total of nine consignments arrived between 1921 and 1926 (Table 39.2); 21 adults and three pupae from Australia (1 November 1922) were released into a Nelson greenhouse in late December 1921 but were not found there by February 1922 (DSIR files); 300 adults and larvae received on 16 December 1922 had all died in the insectary by July 1923 (DSIR files). Nine adults from the U.S.A. (28 August 1923) were released in Hastings. The remainder of the shipment (24 pupae and one larva) was combined with another Australian lot (15 November 1923) of several hundred larvae and pupae, and reared. These were then released to Auckland, Hastings (around 500), Blenheim and Motueka (around 450) in 1924 (DSIR files, Miller 1924). Only 42 adults survived from a shipment from California (18 February 1924) and were all sent to Motueka; 36 adults and one larva from Australia (19 November 1924) were bred and 50 adults sent to Hawke's Bay; and 72 larvae and pupae from Australia (9 December 1925) were kept until adults emerged, but their fate is not recorded (DSIR files). Finally, two lots of *C. montrouzieri* arrived from California (November 1925 and December 1926) with mixed consignments of mealybug predators and parasitoids, but were dead on arrival in New Zealand (DSIR files). In summary, limited releases of *C. montrouzieri* were made in 1923 (Miller 1924), further releases were made in Auckland, Hastings, Blenheim and Motueka in 1924 (Miller 1925) and in 1926 it was considered to be established in Hawke's Bay and Whangarei (Cockayne 1926). No releases were made in 1927 because *C. montrouzieri* was so well established in Whangarei that it was considered that any further specimens could more easily be collected from there if necessary (Cockayne 1927).

C. montrouzieri remains locally common from Auckland northwards, especially in unsprayed citrus orchards, where it may still be an important mealybug predator. It has not been recorded from other horticultural regions of New Zealand for many years. The inability of *C. montrouzieri* to persist in cool climates, a feature noted throughout the many countries to which the species has been sent, has markedly restricted the long term effectiveness of this ladybird against mealybugs in New Zealand.

Coccophagus gurneyi Compere (Hymenoptera: Aphelinidae)

In August 1927, H. Compere, from the Citrus Experimental Station at Riverside, California, arrived in Australia to search for natural enemies of *P. calceolariae* (then *P. gahani* Green). In this he was successful, and returned to the U.S.A. with colonies of *Coccophagus* n. sp., *Tetracnemus* n. sp., *Diplosis* sp., *Pullus* sp., *Diomus* sp., and *Chrysopa* sp. (Smith & Compere 1928).

Compere returned to California via New Zealand. He arrived in Wellington on 27 February 1928 and arranged for a fresh supply of mealybugs for his predator colonies. These were supplied by D. Miller (Government Biologist in Wellington) and in return, Compere left some of the predators in New Zealand (Table 39.3). These were taken to the Cawthron Institute later in the year when Miller transferred there, but were not released (DSIR files). On 18 December 1928, the Cawthron Institute received a further consignment from Compere's Australian collection (Table 39.3). It can be inferred that the natural enemies recorded as *Coccophagus*, and *Tetracnemus*, were, in fact, *C. gurneyi* and *Tetracnemoidea brevicornis* (= *Tetracnemus pretiosus*).

These were put into the Cawthron Institute insectary, but by October 1929 all had died. No releases were made during this period (DSIR files).

Table 39.3 Consignments of *Coccophagus gurneyi* to New Zealand.

Date	Species/Consignment	Source	Reference
27 February 1928	*Coccophagus* n. sp. *Tetracnemus* n. sp. *Diplosis* sp. *Pullus* sp. *Diomus* sp. *Chrysopa* sp.	Australia	Clausen 1978, DSIR files
18 December 1928	*Coccophagus* sp. *Tetracnemus* sp. *Diplosis* sp. *Pullus* sp. *Chrysopa ramburi*	California, U.S.A.	DSIR files
3 February 1933	*Coccophagus gurneyi*	Riverside, California, U.S.A.	DSIR files, Miller 1934

In early February 1933 a further shipment (four females and one male) of *C. gurneyi* was received at the Cawthron Institute from California, and from this small population a thriving colony was started (DSIR files). Liberations were made in different parts of New Zealand during the latter half of the 1933-34 and 1934-35 season (Miller 1934). About 27,000 parasitoids were subsequently liberated in the Nelson district and in the North Island from the Lower Hutt to the Bay of Islands (Miller 1963). Parasitoids were also sent to Samoa, the Cook Islands (Miller 1934), and Niue (DSIR files). *C. gurneyi* is now widespread through New Zealand, despite the original extremely small gene pool.

Chrysopa spp., *Chrysopa ramburi* Schneider (Neuroptera: Chrysopidae)

Several species of *Chrysopa* are known to be generalist feeders of mealybugs and scale insects. *Chrysopa* spp. which are predators of mealybugs and scale insects (as distinct from aphid predators) have been introduced into New Zealand from Australia on at least two occasions. There is some evidence that all the shipments were, in fact, *C. ramburi*, which is native to Australia. It had been recorded as a scale insect predator at least by 1892

(Anonymous 1892) and was introduced into California in 1928 (along with other Australian natural enemies) to help control *Pseudococcus calceolariae* (Compere & Smith 1932).

Chrysopa sp. was previously introduced to California from South Australia in 1889 (Koebele 1890). Koebele re-visited Australia in 1891, and spent several weeks in New Zealand on the way. At this time he released various North American predators of 'blights', including some pupae of *Chrysopa* sp. (Anonymous 1891). It is not clear whether these were native American species, or descended from those collected in Australia in 1889. Nevertheless, Broun (1898) recorded *Chrysopa* sp. feeding on mealybugs in Auckland and Whangarei.

Two consignments of *Chrysopa* sp. also arrived from Australia in 1921, on 26 October and 1 November (together with *Cryptolaemus montrouzieri*) (DSIR files). 'Many' larvae and pupae were received, feeding on a mealybug colony on *Acacia decurrens*, together with jars of adults and eggs. Eggs and larvae were reared on mealybugs and *Icerya* sp. Thirty five adults and about 75 larvae were released in Nelson during November and December 1921, but were not subsequently recovered (DSIR files).

Twenty one cocoons of *Chrysopa ramburi* Schneider (from a colony established from Australia) arrived from California on 18 December 1928 together with an assortment of mealybug parasitoids and predators (Table 39.3), but they had all died by 16 January 1929 (DSIR files).

Chrysopa species predatory on mealybugs (or scale insects) are not known in New Zealand at present so it seems that none of the early releases have been successfully established. However, there was never a concerted effort to establish mealybug feeding *Chrysopa* species. *C. ramburi* and *Chrysopa* sp. are known to feed on *Pseudococcus longispinus* in Australia (Turner 1976, Wilson 1960) and *Chrysoperla plorabunda* Fitch (= *californica* Coquillett) have been associated with *Planococcus citri* in California (Bartlett 1957). Thus, together with hemerobiid neuropterans (*q.v.*), *Chrysopa* spp. may form a useful component of the natural enemy complex of mealybugs.

Although the effectiveness of natural enemies released for mealybug control has never been subsequently measured, Miller (1945) commented that the influence of all natural enemies was insufficient for commercial purposes.

Other importations

Between February 1924 and December 1926 a total of five shipments of assorted mealybug natural enemies arrived in New Zealand from California. The consignments contained natural enemies that were effective against mealybug pests (especially *Planococcus citri*) in California at the time. Shipments were organised by D. Miller, Director of the Cawthron Institute, and came from H.S. Smith & H.M. Armitage (Citrus Experimental Station, Riverside) or C.F. Dodds (Santa Paula Citrus Fruit Association). All mealybug predators and parasitoids from these consignments were placed in an insectary at the Cawthron Institute, but none survived. Many, and sometimes all, were dead upon arrival in New Zealand. There were no releases from any of these shipments (DSIR files). Because their importation was recorded (Miller 1924, Miller *et al.* 1936) and can been misconstrued as 'introduced' (e.g. Noyes 1988), further details of arrival dates in New Zealand, and the contents of the consignments are given in Table 39.4. *Leptomastidea abnormis* (Girault), introduced into California from Sicily in 1914/15 and subsequently distributed widely elsewhere, is principally a parasitoid of *P. citri*.

No other enemies of mealybugs have been imported into New Zealand, although interest in the biological control of mealybugs remained for several years after the establishment of *Coccophagus gurneyi*. During the season of 1946-47, collections of mealybugs from different plants were made and sent to California for verification of identity, with the objective of importing the most worthwhile natural enemy against New Zealand mealybugs (Cawthron Institute 1947). No records exist of subsequent events. In September 1946, D. Miller

Table 39.4 Consignments of miscellaneous mealybug natural enemies to New Zealand. No releases made. Insects imported on 16 February 1924 and 26 November 1925 accompanied consignments of *Cryptolaemus montrouzieri*

16 February 1924	
	Leptomastix abnormis (Girault) (Hymenoptera: Encyrtidae)
	Scymnus binaevatus Mulsant (Coleoptera: Coccinellidae)
9 June 1925	
	Paraleptomastix abnormis (= *L. abnormis*)
	Exochomus nigromaculatus (Goeze) (Coleoptera: Coccinellidae)
	Sympherobius californicus Banks (Neuroptera: Chrysopidae)
	S. barberi (Banks) (Neuroptera: Chrysopidae)
26 November 1925	
	Paraleptomastix abnormis
	Harmonia (= *Leis*) sp. (Coleoptera: Coccinellidae)
	Scymnus sp.
	Sympherobius sp.
7 January 1926	
	Paraleptomastix sp.
	Scymnus binaevatus
	S. sordidus Horn
	Harmonia (= *Leis*) sp.
	Sympherobius sp.
21 December 1926	
	Tanaomastix abnormis (= *P. abnormis*)
	Scymnus sordidus
	S. binaevatus
	Cryptolaemus sp.

requested information on Canadian parasitoids for importation into New Zealand (DSIR files), but again, no action was recorded.

Evaluation

Biological control of mealybugs by natural enemies can be achieved. In California, the control of *Pseudococcus calceolariae* by the combined activity of two introduced parasitoids, *Coccophagus gurneyi* and *Tetracnemoidea brevicornis*, is considered to be one of the most successful operations against a serious pest in the history of the State. Bartlett (1969) evaluated about 20 biological control campaigns against mealybugs worldwide. He concluded that success probably depended on having a range of natural enemies which could survive on several different hosts throughout a range of climatic conditions, and which responded quickly to various initial host densities, rather than on having one or two parasitoids which developed synchronously with their host.

The historical events leading to the presence of mealybug pest species and their natural enemies in New Zealand, either through deliberate introductions or from accidental or natural events, are closely and almost exclusively linked to Australia and California. The three most important mealybug species in New Zealand – *P. calceolariae*, *P. affinis* and *P. longispinus* – are all polyphagous and occur over a wide range of climatic conditions. They are Australian or American natives, and are also pests in California. Successful biological control programmes against *P. calceolariae* and *P. longispinus* were undertaken in California, largely using natural enemies collected from Australia. No biological control work has been

undertaken against *P. affinis per se*, but until recently, this species was not distinguished taxonomically from the North American native *P. maritimus*. Extensive work has been carried out on the biological control of *P. maritimus*, especially with native natural enemies, and at least some of these are likely to have been killing *P. affinis* as well. New Zealand benefitted from the excellent co-operation among entomologists in all three countries during the first half of the century and natural enemies originating from both Australia and North America were supplied from California. However, pest priorities in New Zealand changed with the advent of DDT, and there has been little subsequent interest in the biological control of mealybugs. There have been no ecological studies on the success of any of the natural enemies of mealybugs in New Zealand, but the possible impact of some can be inferred from publications from California and Australia.

Cryptolaemus montrouzieri has been shown to be a voracious predator on many species of mealybug throughout the world, but it is strictly limited by cooler climatic conditions, and in New Zealand it is now restricted to areas north of Auckland. Its current impact on mealybugs in northern orchards is unknown but it is perhaps significant that mealybugs are not usually a pest on unsprayed citrus trees in Northland (D. Steven pers. comm.).

Coccophagus gurneyi is also polyphagous, but shows at least some host specificity. For example, whereas it is held to be successful (with *T. brevicornis*) in controlling *P. calceolariae* (Bartlett 1978), both Flanders (1940) and DeBach (1949) found few of them on *P. longispinus* compared with other parasitoids. Bess (1939) recorded that most *C. gurneyi* larvae gradually disintegrated within the body fluids of that host but Charles (unpublished data) has reared *C. gurneyi* from adult female *P. longispinus* on apple trees in New Zealand. *C. gurneyi* has established widely in New Zealand, but no studies of its impact on pseudococcid populations have been carried out. In combination with the self-introduced *T. brevicornis* it is likely to have a considerable impact on *P. calceolariae*, at least in tree crops, as it does in California. Charles (unpublished data) has reared *C. gurneyi* from *P. calceolariae* on apple trees. Adult parasitoids have emerged from third instar and adult females or unidentified second instar male cocoons.

There have been no attempts to introduce natural enemies specifically for *P. longispinus* control into New Zealand. Elsewhere, important parasitoids of *P. longispinus* are *Tetracnemoidea sydneyensis*, *T. brevicornis*, *C. gurneyi* and *T. peregrina* in California (DeBach 1949, Flanders 1940); *Anagyrus fusciventris* (Girault) and *T. sydneyensis* in South Australia (Furness 1976); and *T. peregrina* and *A. fusciventris* in Israel (Swirski *et al.* 1980). Of this rather limited range of four encyrtid and one aphelinid species, only *T. brevicornis* and *C. gurneyi* are widespread in New Zealand. *T. sydneyensis* is a recent arrival, and is probably restricted to Auckland. *T. peregrina* is doubtfully present, and *A. fusciventris* has never been recorded. Valentine (1963) recorded *Anagyrus* sp. from *Pseudococcus* sp. in Tauranga, but this was a misidentification of *Gyranusoidea advena* (Noyes 1988). Further study of the biology of these natural enemies under different crop and climatic regimes, with a view to importing the most efficient ones into New Zealand would undoubtedly be beneficial.

The recently recognised *P. affinis* is a cosmopolitan species, probably of Australian origin (Williams 1985). No-one has searched for natural enemies in Australia, probably because for many years it was not distinguished from the closely related *P. maritimus*, a North American native not present in Australasia. American natural enemies of *P. maritimus* probably attack *P. affinis* as well, but so far none has been considered for importation into New Zealand. Doutt & Hagen (1950) reported that *P. maritimus* on pear was rarely attacked by parasitoids compared with the 'grape race' in California, and that *Chrysopa californica*, the dominant predator, could suppress the mealybug populations. *C. californica* has not established in New Zealand (see Chapter 11).

Evaluating the effects of natural enemies on mealybugs in commercial crops in New Zealand is difficult. It is usually accepted that natural enemies alone would be incapable of giving sufficient control of mealybugs because there is a nil- or low-tolerance for pests on most of New Zealand's fresh fruit exports. To achieve these standards they are currently

sprayed with insecticides. The insecticides used against mealybugs and other horticultural pests are usually very toxic to natural enemies (especially hymenopterous parasitoids), which are consequently uncommon before harvest. Nevertheless, mealybugs are widespread on non-economic host plants or in unsprayed environments, and there is potential for these habitats to act as reservoirs of natural enemies which could improve control in commercial crops when spray residues were low enough.

On processing crops – particularly in vineyards producing wine grapes - a low population level of mealybugs is acceptable. In these environments, which generally receive few pesticide applications, natural enemies may already be quite effective, and the addition of further species may be of considerable practical value.

Conclusions

There have been no deliberate introductions of mealybug natural enemies into New Zealand since 1933. In the intervening 55 years the taxonomy of mealybugs has been greatly clarified, and there have been many studies of the natural enemy complexes of mealybugs in other countries. There is now a wealth of information which could be used to improve the present level of mealybug biological control in New Zealand. The following recommendations can be made:

1) General:- Further studies should be initiated to document the identity, geographical distribution, host range and preference of the natural enemies of the three economically important species of mealybug on horticultural crops in New Zealand. At the same time, the pest status of these mealybugs on different crops in different regions, and the opportunities for reducing pesticide applications toxic to natural enemies, should be evaluated. The effectiveness of existing enemies, especially predators, should be evaluated in unsprayed environments. The species of *Ophelosia*, which are common among New Zealand mealybugs, should be described, characterised and compared with *O. crawfordi* Riley, a common predator in Australia (Wilson 1963), and the biology of these and *Cryptoscenea australiensis* – together the commonest mealybug predators – should be elucidated. The identity of secondary parasitoids, their impact on primary parasitoids (or predators), and their distribution in New Zealand, should also be studied.

2) *Pseudococcus longispinus*:- Because this species is commonly a pest in vineyards where pesticide use is minimal compared with other crops, and where a low population level is acceptable, steps should be taken to evaluate known natural enemies from Australia and possibly California with a view to their introduction into New Zealand. First candidates should be *Anagyrus fusciventris*, *Tetracnemoidea sydneyensis*, *T. brevicornis* and *Chrysopa ramburi*, from Australia, *Sympherobius californicus* and *C. californica* from California, U.S.A., and *T. peregrina*.

3) *Pseudococcus affinis*:- A search for natural enemies of this species in Australia and the U.S.A. would be worthwhile. Because of their close similarity, effective natural enemies of *P. maritimus*, native to the U.S.A., should also be considered for importation to New Zealand.

4) *Pseudococcus calceolariae*:- *Coccophagus gurneyi* and *T. brevicornis* are well established in New Zealand. *C. gurneyi* is common, but the status of *T. brevicornis* is unclear. These two species together have been effective against this mealybug species in California. If *T. brevicornis* is uncommon in New Zealand, further deliberate introductions from California should be considered.

Acknowledgements

I thank W.D. Pearson and W.P. Thomas for information on *Balanococcus poae* and *Planococcus mali* respectively.

Literature Cited

Anonymous (1891) Insect police from America. *New Zealand Farmer, October* , 414.

Anonymous (1892) The saltbrush scale of Australia. *Insect life* 4, 408.

Atkinson, J.D. (1940) Progress report on the control of mealybug on pears. *Orchardist of New Zealand* 13(8), 135.

Bartlett, B.R. (1969) The biological control campaigns against soft scales and mealybugs on citrus in California. *Proceedings of the 1st International Citrus Symposium, Riverside* 2, 875-87.

Bartlett, B.R. (1978) Pseudococcidae. Pp. 137-170 in Clausen, C.P. (ed.), Introduced parasites and predators of arthropod pests and weeds. A world review. *United States Department of Agriculture, agriculture handbook* 480.

Bartlett, B.R. (1957) Biotic factors in natural control of citrus mealybugs in California. *Journal of economic entomology* 50, 753-755.

Bartlett, B.R.; Lloyd, D.C. (1958) Mealybugs attacking citrus in California – a survey of their natural enemies and the release of new parasites and predators. *Journal of economic entomology* 51, 90-93.

Bess, H.A. (1939) Investigations on the resistance of mealybugs (Homoptera) to parasitization by internal hymenopterous parasites, with special reference to phagocytosis. *Annals of the Entomological Society of America* 32, 189-226.

Broun, T. (1896) Annual report. *Report of the New Zealand Department of Agriculture* 4, 155.

Broun, T. (1897) Annual report. *Report of the New Zealand Department of Agriculture* 5, 150.

Broun, T. (1898) Annual report. *Report of the New Zealand Department of Agriculture* 6, 217, 218-219.

Cawthron Institute (1947) Entomological investigations, mealy-bugs. Annual report 1946-47, p. 33.

Charles, J.G. (1981) Distribution and life-history of the long-tailed mealybug, *Pseudococcus longispinus* (Homoptera: Pseudococcidae), in Auckland vineyards. *New Zealand journal of zoology* 8, 285-293.

Charles, J.G. (1982a) Economic damage and preliminary economic thresholds for mealybugs (*Pseudococcus longispinus* T.-T. Homoptera: Pseudococcidae) in Auckland vineyards. *New Zealand journal of agricultural research* 25, 415-420.

Charles, J.G. (1982b) Commercial control of mealybugs in apple orchards. *Orchardist of New Zealand* 55, 298-299.

Charles, J.G. (1985) *Diadiplosis koebelei* Koebele (Diptera: Cecidomyiidae), a predator of *Pseudococcus longispinus* T.-T. (Homoptera: Pseudococcidae), newly recorded from New Zealand. *New Zealand journal of zoology* 12, 331-333.

Charles, J.G.; Walker, J.T.S. (1981) Mealybug control in apples. *Orchardist of New Zealand* 54, 252-253.

Clausen, C.P. (1978) Introduced parasites and predators of arthropod pests and weeds: a world review. *United States Department of Agriculture, agriculture handbook* 480, 545 pp.

Cockayne, A.H. (1926) Report of Fields Division. *Report of the New Zealand Department of Agriculture 1926*, 33.

Cockayne, A.H. (1927) Report of Fields Division. *Report of the New Zealand Department of Agriculture 1927*, 39.

Collyer, E.; van Geldermalsen, M. (1975) Integrated control of apple pests in New Zealand. (1) Outline of experiment and general results. *New Zealand journal of zoology* 2, 101-134.

Compere, H.; Flanders, S.E. (1934) *Anarhopus sydneyensis* Timb., an encyrtid parasite of *Pseudococcus longispinus* (Targ.) recently introduced into California from Australia. *Journal of economic entomology* 28, 966-973.

Compere, H.; Smith, H.S. (1932) The control of the citrophilus mealybug, *Pseudococcus gahani*, by Australian parasites. *Hilgardia* 6, 585-618.

Congdon, N.B.; Morrison, L.G. (1959) Mealybug resurgence in Hawke's Bay Orchards. *New Zealand journal of agriculture* 99, 481-487.

Cox, J. (1977a) Survey of mealybug species (Homoptera: Pseudococcidae) in Auckland orchards and vineyards. *New Zealand journal of agricultural research* 20, 259-261.

Cox, J. (1977b) Status of New Zealand records of *Pseudococcus comstocki* and *P. maritimus* (Homoptera: Pseudococcidae). *New Zealand journal of zoology* 4, 165-166.

Cox, J. (1987) Pseudococcidae (Insecta: Hemiptera). *Fauna of New Zealand* 11, 228 pp.

DeBach, P. (1949) Population studies of the long-tailed mealybug and its natural enemies on citrus trees in Southern California, 1946. *Ecology* 30, 14-25.

Doutt, R.L.; Hagen, K.S. (1950) Biological control measures applied against *Pseudococcus maritimus* on pears. *Journal of economic entomology* 43, 94-96.

DSIR, Entomology Division, file BC 1/4.

Emms, L.M. (1981) Citrus mealybug. Biology, significance and control. *Aglink* HPP158, 2 pp.

Flanders, S.E. (1940) Biological control of the long-tailed mealybug, *Pseudococcus longispinus*. *Journal of economic entomology* 33, 754-759.

Furness, G.O. (1976) The dispersal, age-structure and natural enemies of the long-tailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti) in relation to sampling and control. *Australian journal of zoology* 24, 237-247.

Gordon, R.D. (1985) The Coccinellidae (Coleoptera) of America North of Mexico. *Journal of the New York Entomological Society* 93, 1-912.

Gourlay, E.S. (1930) Preliminary host-list of the entomophagous insects in New Zealand. *DSIR Bulletin* 22, 1-13.

Kimmins, D.E.; Wise, K.A.J. (1962) A record of *Cryptoscenea australiensis* (Enderlein) (Neuroptera: Coniopterygidae) in New Zealand, with a redescription of the species. *Transactions of the Royal Society of New Zealand (Zoology)* 2, 35-39.

Kirk, T. (1897) Annual report. *Report of the New Zealand Department of Agriculture 1897*, 127.

Kirk, T.; Cockayne, A.H. (1909) Scale insects in New Zealand. *Report of the New Zealand Department of Agriculture 1909*, 273-285.

Koebele, A. (1890) Report of a trip to Australia to investigate the natural enemies of the fluted scale. *United States Department of Agriculture, Division of Entomology, bulletin* 21. 32 pp.

Miller, D. (1924) The mealy-bug pest in orchards. Control by *Cryptolaemus* ladybird. *New Zealand journal of agriculture* 28, 163-165.

Miller, D. (1925) Control work on mealy-bug and pear midge. *New Zealand journal of agriculture* 30, 76.

Miller, D. (1934) Mealy-bugs. Their life-history and control. *Cawthron Institute bulletin* 6, 3 pp.

Miller, D. (1945) Garden pests in New Zealand (2nd ed). Whitcombe and Tombs, Christchurch, New Zealand. 149 pp.

Miller, D. (1963) Thomas Cawthron and the Cawthron Institute. Cawthron Institute Trust Board, Nelson, New Zealand. 248 pp.

Miller, D.; Clark, A.F.; Dumbleton, L.J. (1936) Biological control of noxious insects and weeds of New Zealand. *New Zealand journal of science and technology* 18, 579-593.

Miller, D.R.; Gill, R.J.; Williams, D.J. (1984) Taxonomic analysis of *Pseudococcus affinis* (Maskell) a senior synonym of *Pseudococcus obscurus* Essig, and a comparison with *Pseudococcus maritimus* (Ehrhorn) (Homoptera: Coccoidea: Pseudococcidae). *Proceedings of the Entomological Society of Washington* 86, 703-713.

Noyes, J.S. (1988) Encyrtidae (Insecta: Hymenoptera). *Fauna of New Zealand* 13, 188 pp.

Potter, A.T. (1899) Annual report. *Report of the New Zealand Department of Agriculture 1899*, 239.

Potter, A.T. (1900) Annual report. *Report of the New Zealand Department of Agriculture 1900*, 335.

Potter, A.T. (1901) Annual report. *Report of the New Zealand Department of Agriculture 1901*, 371.

Sale, P.R.; Steven, D. (1985) Insect control trials on persimmons. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 203-206.

Smith, H.S.; Compere, H. (1928) The introduction of new insect enemies of the citrophilous mealybug from Australia. *Journal of economic entomology* 21, 664-669.

Swirski, E.; Izhar, Y.; Wysoki, M.; Gurevitz, E.; Greenberg, S. (1980) Integrated control of the long-tailed mealybug, *Pseudococcus longispinus* (Hom; Pseudococcidae) in avocado plantations in Israel. *Entomophaga* 25, 415-426.

Timberlake, P.H. (1929) Three new species of the hymenopterous family Encyrtidae from New South Wales. *University of California Publications in Entomology* 5(2), 5-18.

Valentine, E.W. (1963) New records of hymenopterous parasites of Homoptera in New Zealand. *New Zealand journal of science* 6, 6-13.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Ward, A. (1966) Mealybugs (Hemiptera: Pseudococcidae) in Hawkes Bay orchards. *New Zealand journal of agricultural research* 9, 452-454.

Williams, D.J. (1985) Australian mealybugs. *British Museum (Natural History), London, Publication* 953, 431 pp.

Williams, D.J.; de Boer, J.A. (1973) The taxonomy of some New Zealand Pseudococcidae (Homoptera:Coccoidea). *Transactions of the Royal Entomological Society of London* 125, 227-252.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Autralasian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Wilson, F. (1963) Australia as a source of beneficial insects for biological control. *Technical bulletin, Commonwealth Institute of Biological Control* 3, 28 pp.

Saissetia oleae (Olivier), black scale (Homoptera: Coccidae)

C.F. MORALES

Pest Status

Black scale, *Saissetia oleae* (Olivier), is believed to have originated from Africa, where it is kept scarce by its natural enemies (Bedford 1978). It is considered to be a major pest of citrus crops throughout the world, but also attacks a wide range of other fruit trees and also ornamental plants (Bartlett 1978). Heavy infestations weaken the plant and often cause stunting of young growth. Major cosmetic damage to fruit is caused by sooty mould growing on the honeydew excreted from the scale (Cottier 1956, Scott 1984).

All stages of the scale are present on the host during winter, and large numbers of eggs are laid under the female scale in November and December. Most of the eggs hatch in December and January. After feeding for four to six weeks the young scales migrate to the woody parts of the plant and become permanently attached. In New Zealand there is usually one generation per year (Scott 1984).

Background

Natural enemies have reduced the importance of this scale from being the most serious pest to the level of a secondary pest on citrus crops in Australia (Wilson 1960), Peru (Wille 1952) and California (Anonymous 1984, Bartlett 1978, Clausen 1978). The successful establishment of polyphagous parasitoids introduced for the control of black scale has also had the unexpected benefit of reducing the importance of other scale pests in California (Bartlett 1978).

Four species have been introduced into New Zealand as biological control agents against black scale. In addition to these, *Coccophagus ochraceus* Howard (Hymenoptera: Aphelinidae), which was introduced for control of mealybugs, also parasitises *S. oleae*. *Euxanthellus philippiae* Silvestri (Hymenoptera: Aphelinidae), *Encyrtus lecaniorum* (Mayr) (Hymenoptera: Encyrtidae) and *Moranila californica* (Howard) (Hymenoptera: Pteromalidae) have also been recorded in New Zealand as parasitising *S. oleae* (Valentine & Walker 1989).

One of the control agents imported into New Zealand was *Rhyzobius forestieri* (Mulsant) (Coleoptera: Coccinellidae). This species was confused with *Rhyzobius ventralis* Erichson until Pope (1981) and Richards (1981) made it clear that it was this species which Koebele sent to California in the 1890s during his second visit to Australia to collect natural enemies to control scales on citrus. Koebele (1893) noted that this ladybird, which he referred to as *R. ventralis*, was 'one of the most numerous of all the Coccinellidae in South Australia and Victoria becoming more rare towards Queensland'. He 'did not recognise the insect at first on this last trip at Sydney, where they were found on various *Lecanium*, on citrus and on other trees. In fact the larvae feeding upon these are much lighter in colour than those feeding on *Eriococcus*' and 'saw in this the most effective enemy for all our *Lecanium*'. Adults of *R. forestieri* resemble those of *R. ventralis* (Pope 1981), but the larvae are usually greenish-yellow, not reddish-brown as in *R. ventralis*. *R. forestieri* feeds on a wide variety of Coccoidea in contrast to *R. ventralis* (Richards 1981). It was first described from Australia as *Scymnodes* (=*Platyomus*) *forestieri* (Mulsant) in 1853 (Pope 1981). There was spectacular initial success with this predator against *Saissetia oleae* in California. A few years later this

diminished (Ebeling 1950), but the beetle still survives in most of the state. Richards (1981) discusses the lack of effectiveness of this predator, stating that contributing causes could be its lack of specificity in food preferences, its inability to produce more generations than its prey, its poor dispersal, and its inability to become established in all the climatic ranges of its host.

The South African wasp *Metaphycus lounsburyi* (Howard) (Hymenoptera: Encyrtidae) oviposits only into the late third instar of the scale. Scale insect control programmes sometimes tend to result in an even hatch of crawlers at certain times of the year, so there is sometimes a shortage of scales of a suitable size for parasitisation. In California, this problem can be helped by planting suitable shelter belt species around citrus orchards which can produce continuous new shoots for *S. oleae* to colonise. This provides the parasitoid with a constant food supply, so that it is present in the orchard when the scales on the citrus are at the right stage for parasitism (Ebeling 1950).

Coccidoctonus dubius Girault (Hymenoptera: Encyrtidae), previously endemic to Australia, was introduced into California in 1901 in the belief that it was a primary parasitoid of *S. oleae* (Bartlett 1978). It proved to be a hyperparasitoid of *M. lounsburyi*. *C. dubius* also reduced the populations of *Moranila californica*, another parasitoid of *S. oleae* in California, which although it was first described from this state, is thought to have originated from Australia (Clausen 1978).

Importations, Releases and Recoveries

Metaphycus lounsburyi (Howard) (Hymenoptera: Encyrtidae)

In 1922 two shipments of parasitised *S. oleae* were sent to the Cawthron Institute, Nelson, from Australia by L. Gallard. From the first shipment only three *M. lounsburyi* and four undetermined chalcidoids emerged. From the second shipment 34 chalcidoids emerged including some *M. lounsburyi*. These, together with all of the adults from the previous shipment, were released in Nelson (DSIR files).

During this period, there was a prolonged biological control programme against black scale in California and its parasitoids were being distributed to many countries (Bartlett 1978). It is possible that in addition to the Australian consignments, there may have been unrecorded importations of this parasitoid from California. Cameron *et al.* (1987) state that *M. lounsburyi* was imported from California although Dumbleton (1936) makes no mention of its origin. *M. lounsburyi* was not known to have become established in New Zealand (Dumbleton 1936) until 1982 when it was recovered from Auckland (Noyes 1988).

Orcus chalybeus Boisduval (Coleoptera: Coccinellidae)

In 1899, *Orcus chalybeus* Boisduval was introduced from Australia and released throughout New Zealand to control black scale (Dumbleton 1936, Kirk 1908). Dumbleton (1936) stated that it was known to exist in the Auckland province but it has now been recovered from Northland, Auckland, Coromandel, Taupo, Tauranga, Gisborne and Nelson (New Zealand Arthropod Collection (NZAC)).

Rhyzobius forestieri (Mulsant) (Coleoptera: Coccinellidae)

Rhyzobius forestieri was introduced in 1899 from Australia as *R. ventralis* (Kirk 1897, 1900). It has become established in both islands of New Zealand (Dumbleton 1936) and has been recovered from most areas of New Zealand, (Pope 1981). Specimens are held in the NZAC.

Microterys flavus (Howard) (Hymenoptera: Encyrtidae),

Scutellista cyanea Motschulsky (Hymenoptera: Pteromalidae) and *Coccidoctonus* (=*Quaylea*) *dubius* (Girault) (Hymenoptera: Encyrtidae).

The first attempt to bring hymenopterous parasitoids into New Zealand against black scale was made in 1921 when a consignment of parasitised *S. oleae* and *Saissetia coffeae* (Walker) was sent to the Cawthron Institute, Nelson, from Australia (DSIR files). Several species of chalcidoid wasps emerged from this shipment and were released around Nelson onto trees infested with black scale. The species released were *Scutellista cyanea* Motschulsky (Hymenoptera: Pteromalidae), *Microterys flavus* (Howard) (Hymenoptera: Encyrtidae) and *Coccidoctonus dubius* (DSIR files).

A second shipment of parasitised *Saissetia oleae* was sent from Australia to Nelson by L. Gallard in 1922. The 34 chalcidoids which were reared and released included *Scutellista cyanea* and *Metaphycus lounsburyi* (see above)

Evaluation

Scutellista cyanea has not become established (Cameron *et al.* 1987, Dumbleton 1936). *Microterys flavus* is now a common parasitoid on *Coccus hesperidum* L., but so far has not been reared from *S. oleae* (Valentine & Walker 1989). *Coccidoctonus dubius* has become established (Valentine 1963). It was introduced into New Zealand in about 1921 (perhaps from California) in the belief that it was a primary parasitoid of *S. oleae*, but it is a parasitoid of *Moranila californica* in *S. oleae* (Valentine & Walker 1989).
M. californica was probably accidentally introduced into New Zealand and has been collected in Northland, Auckland and Nelson. Specimens are held in the NZAC.

In New Zealand black scale is considered to be of minor importance in orchards but occasionally it can be the most important citrus orchard pest (D. Steven pers. comm.). No evaluation has been made of the impact of natural enemies on populations of this scale in New Zealand.

Conclusions

Any further introductions to control this pest in New Zealand could include the parasitoid *Metaphycus helvolus* (Compere) (Hymenoptera: Encyrtidae). This species has several attributes which make it particularly suitable for consideration as a biological control agent (Clausen 1978, Ebeling 1950);

1) Ovipositing females feed on the body contents of the scale, often causing greater mortality than by parasitism alone and none of the scales parasitised produce offspring.
2) Adult parasitoids are long-lived with an oviposition period (in California) lasting three months or more.
3) Females have a high reproductive capacity.
4) Parasitoids develop quickly (13 days from egg to adult).
5) There are up to eight parasitoid generations during each scale generation.
6) Only one egg is deposited in each host.
7) High searching ability means that parasitoids are effective at low host densities, which in turn means that they are not easily found by hyperparasitoids.

However, as explained by Bartlett (1978), evidence for the existence of different physiological strains of *S. oleae*, each with specific parasitoids, makes the possibility of parasitoid adaptation and establishment less certain (Ebeling 1950). A disadvantage is that where ants attend the scales they interfere with the oviposition of the parasitoid (Anonymous 1984).

M. helvolus was introduced into California from South Africa and from 1937-1948 was the major parasitoid of black scale, reducing it to its lowest recorded levels. Factors involved in its decline from 1948 are obscure; adverse winter conditions are thought to be one reason (Bartlett 1978). In spite of this, *M. helvolus* is still regarded as providing substantial control

of black scale, especially in coastal regions and those areas with mild winters where overlapping generations of the host provide scales of suitable size for parasitism (Anonymous 1984). Thus, it would appear to be of potential use to New Zealand citrus and subtropical orchards, but a thorough investigation would be needed to select the right race of parasitoid for New Zealand conditions.

In comparison with Australia (Wilson 1960) and California (Clausen 1978), New Zealand has few parasitoids and predators of this scale. In the absence of any analysis of the impact of natural enemies, it is difficult to say whether further introductions of selected parasitoids or predators will be of benefit. A detailed knowledge of the scale's life history and seasonality is essential before any such introductions are considered.

Literature Cited

Anonymous (1984) Insects, mites and snails. Pp. 49-109 in Integrated pest management for citrus. University of California statewide integrated pest management project, Division of Agriculture and Natural Resources publication 3303.

Bartlett, B.R. (1978) Coccidae. Pp. 57-74 in Clausen, C.P. (ed.) Introduced parasites and predators of arthropod pests and weeds: a world review. *United States Department of Agriculture, Agriculture Research Service, Agriculture handbook* 480.

Bedford, E.C.G. (1978) (ed.) Other scale insects of minor importance. In Citrus pests in the Republic of South Africa. *Department of Agricultural Technical Services* 391. 253 pp.

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination and for dung dispersal. *DSIR bulletin* 242, 51 pp.

Clausen C.P. (1978) Biological control of citrus insects. Pp. 274-317 in Reuther, W.; Calavan, E.C.; Carman, G.E. (eds) The citrus industry, volume iv. Division of Biological Sciences, University of California, Berkeley.

Cottier, W., (1956) Insect pests. Pp. 211-441 in Plant protection in New Zealand. Government Printer, Wellington.

DSIR, Entomology Division, file BC 1/4.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Ebeling, W. (1950) Subtropical entomology. Lithotype Process Co., San Francisco, California. 747 pp.

Kirk, T.W. (1897) Fifth Report of the Department of Agriculture. Wellington, New Zealand. p. 127.

Kirk, T.W. (1900) Eighth report of the Department of Agriculture. Wellington, New Zealand. p. 281.

Kirk, T.W. (1908) 'Gum-tree blight' and the natural enemy. *Report of the Department of Agriculture, New Zealand* 117-122.

Koebele, A. (1893) Studies of parasitic and predaceous insects in New Zealand, Australia and adjacent islands. *United States Department of Agriculture report* 51, 39 pp.

Noyes, J.S. (1988) Encyrtidae (Insecta: Hymenoptera). *Fauna of New Zealand* 13, 188 pp.

Pope, R.D. (1981) '*Rhizobius ventralis*' (Coleoptera: Coccinellidae), its constituent species, and their taxonomy and historical roles in biological control. *Bulletin of entomological research* 71, 19-31.

Richards, A.M., (1981) *Rhyzobius ventralis* (Erichson) and *R. forestieri* (Mulsant) (Coleoptera: Coccinellidae), their biology and value for scale insect control. *Bulletin of entomological research* 71, 33-46.

Scott, R.R. (ed.) (1984) New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Valentine, E.W. (1963) New records of hymenopterous parasites of Homoptera in New Zealand. *New Zealand journal of science* 6, 6-13.

Valentine, E.W.; Walker, A.K. (1989) Annotated catalogue of New Zealand Hymenoptera. *DSIR bulletin* 246, in press.

Wille, J.E. (1952) Entomologia Agricola del Peru. Ed. 2, Ministerio de Agricultura Junta de Sanidad Vegetal. Lima, Peru. 544 pp.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Scolypopa australis (Walker), passionvine hopper (Homoptera: Ricaniidae)

R.L. HILL and D. STEVEN

Pest Status

Scolypopa australis (Walker) (Homoptera: Ricaniidae), or passionvine hopper, is native to Australia but was first recorded in New Zealand in 1878 (Distant 1878). Broun (1896) later described it as being 'almost ubiquitous' in the north and recalled seeing it on forest shrubs 20 years previously. It has probably been imported on many occasions as eggs in plant material (Cumber 1966). It is very common north of about 38°S and occurs in warmer areas further south (Cumber 1966). It is a phloem-feeding bug which, if present in sufficient numbers, can cause general debility, stunting and wilting of the host plant. Copious quantities of sticky honeydew are produced and this can cause sooty moulds to grow over the plant surface. Although, as its name implies, passionvine hopper can be abundant on *Passiflora edulis* Sims in northern New Zealand, nymphs and adults have been recorded damaging an extremely wide range of host plants growing in a wide range of habitats (Cumber 1986, Dietz 1981, DSIR files, Spiller & Wise 1982). These include kiwifruit, an economically important crop, fruit of which can become contaminated by sooty moulds. Siew (1960) lists 37 species of native plants attacked and the severity of damage caused to them.

Nymphs emerge from overwintering eggs between October and February. Most authors have considered such eggs to be in diapause, but Fletcher (1978) found that development of the eggs continued slowly throughout the winter. There are five nymphal instars which range in size from 1 to 5 mm. Nymphs are pale, with brown markings, and carry a tuft of white waxy filaments which point up from the tip of the abdomen. Nymphs hop vigorously if disturbed. The first adults appear in late December in warmer climates and those emerging later can survive until June. They have brown, transparent forewings and resemble moths (Dietz 1981). They can fly as well as jump. Normally adults are present from January to April, nymphs from November to March.

Eggs are inserted in rows into small plant stems with dead or dying pithy twigs being preferred. Many host plants are used. Eggs can be laid near the ground or high in trees. Although the eggs are not visible, the oviposition site is easily seen because it is plugged by a characteristic mass of pulped plant fibres. Further information about the life history and importance of *S. australis* can be found in Cumber (1966, 1967), Dietz (1981), Scott (1984) and Steven (in press).

Feeding by *S. australis* on the indigenous toxic shrub tutu, *Coriaria arborea* Lindsay (Coriariaceae), can lead to large amounts of honeydew containing the toxin. When gathered by bees, toxic honey is produced. Such honey has caused numerous cases of poisoning in New Zealand including several fatalities (Palmer-Jones 1947, Patterson 1947). This has led to restrictions on beekeeping activities in some areas (Bryant & Matheson 1984).

Background

Cumber (1966) surveyed the factors affecting *S. australis* populations in New Zealand as a prelude to searches in Australia for possible biological control agents. Nymphs and adults appeared to be free of parasitoids. Spiders preyed on both nymphs and adults while the German wasp, *Vespula germanica* (F.) (Hymenoptera: Vespidae) was observed capturing adults. The importance of such predation on *S. australis* populations is uncertain. He found

three unidentified fungi infecting adults (Cumber 1966). Siew (1960) had previously found the fungal pathogens *Trichothecium roseum* (Pers.) Link, *Hymenostilbe* spp., and *Hirsutella citriformis* Speare attacking *S. australis*. Siew also noted predation by spiders.

Cumber (1966) described a detailed survey of mortality factors affecting eggs. The naturalised aphelinid parasitoid *Centrodora scolypopae* Valentine (Hymenoptera: Aphelinidae) was the most significant biological factor affecting survival. Up to 87% of eggs collected north of Auckland were parasitised, with a mean of 39%. In cooler areas this proportion decreased and the parasitoid was absent from Nelson. A small percentage of eggs was destroyed by a predatory pyemotid mite, *Pyemotes* sp. Further information about the relationship between *C. scolypopae* and its host can be found in Gerard (1985).

In 1965, Cumber collected *S. australis* near Sydney, Australia, to look for potential biological control agents for establishment in New Zealand. *C. scolypopae* parasitised only 3 to 4% of eggs at three sites compared with up to 87% in northern New Zealand. An unidentified scelionid species parasitised 17, 10 and 0% of the eggs collected in three samples (Cumber 1967). Fletcher (1978) also collected eggs near Sydney but recorded only 7.2% parasitism.

Other species are also known to attack *S. australis* in Australia (DSIR files) including a chrysopid species which Cumber (1967) observed preying on eggs. Common (1970) recorded that larvae of the epipyropid moth *Heteropsyche* sp. were predacious on *S. australis* but Cumber (DSIR files) suspected that the epipyropid which he saw was feeding on honeydew. English (1964) found that *Heteropsyche melanochroma* Perkins did not appear to harm hoppers. The true relationship between these moths and *S. australis* remains uncertain.

Cumber (DSIR files) suggested that further searches in Australia for control agents should be carried out south of Sydney. In 1981, D. Steven sought possible control agents in Queensland, New South Wales and Victoria (DSIR files). *S. australis* was very uncommon at most sites (including some visited by R.A. Cumber), but he collected a dryinid parasitoid of nymphs in Melbourne, and at another site near Sydney he collected a specimen killed by the fungus *Hirsutella* probably *versicolor* Petch.

Importations, Releases and Recoveries

During his visit to Australia in February and March 1965, Cumber (1967) collected *S. australis* eggs embedded in twigs of various host plants. These were transferred to a quarantine facility in New Zealand and yielded two primary parasitoids. More than 200 *Centrodora scolypopae* emerged and were used to parasitise *S. australis* eggs of New Zealand origin but there is no record of any subsequent releases. An unidentified scelionid parasitoid also emerged and adults were used to parasitise further *S. australis* eggs. Over three occasions in March 1965, a total of 377 of the 637 scelionids which emerged from imported eggs was released at Paihia. Although a laboratory culture was initiated, it is not known whether further releases were made.

Cumber was able to collect 240 eggs of an unidentified chrysopid near Sydney, despite heavy parasitism. These were transferred to New Zealand and reared in quarantine. In March 1965, 140 larvae were released at Paihia and there was evidence that adults emerged in early May. Later in the summer a further 60 adults were released at the same site. A detailed report of the importation, rearing and release of all three control agents was prepared by Cumber (DSIR files).

In 1981, 60 pupae of an unidentified dryinid parasitoid of *S. australis* nymphs were collected in Melbourne (D. Steven DSIR files). These were reared in quarantine in New Zealand, but few adults emerged. Several hyperparasitoids were produced and were destroyed (Entomology Division 1982).

Evaluation

The aphelinid egg parasitoid *Centrodora scolypopae* probably entered New Zealand from Australia many years ago in parasitised eggs embedded in plant material. It can parasitise a high proportion of *S. australis* eggs in New Zealand, especially in warmer climates. It is not known how this level of parasitism affects the population dynamics of the pest.

In the Sydney area, the unidentified scelionid parasitised a greater proportion of *S. australis* eggs than did *C. scolypopae* (Cumber 1967). Unfortunately, this species failed to become established in New Zealand (R.A. Cumber DSIR files). He also considered the chrysopid species to be an important predator of the passionvine hopper in Australia, but it too failed to establish (Cumber 1965, DSIR files). This chrysopid species joins a long list of Chrysopidae which have been released in New Zealand to prey on pest Homoptera but which failed to establish (Chapter 11).

Conclusions

S. australis remains a moderately serious pest in New Zealand. It is susceptible to most insecticides but reinfestation after spraying is common. It causes few problems on crops subjected to regular insecticide applications, but passionvine hopper causes significant damage in home gardens, on ornamental species, and on other plants which are not normally sprayed.

It appears that endemic populations in Australia are much lower than those which occur in New Zealand. One reason for this difference may be the wide range of parasitoids, predators and diseases of *S. australis* which has been recorded there, some of which have been discussed in this chapter. There seem to be as yet unexplored opportunities for biological control of this pest in New Zealand.

Acknowledgements

This chapter draws heavily on unpublished data prepared by R.A. Cumber (DSIR files).

Literature Cited

Broun, T. (1896) *Report of the New Zealand Department of Agriculture* 4, 156.

Bryant, T.G.; Matheson, A.G. (1984) Beekeeping: toxic honey from tutu. *Aglink* FPP 827, 3 pp.

Common, I.F.B. (1970) Lepidoptera. Pp. 765-866 in Insects of Australia. Melbourne University Press, Australia. 1029 pp.

Cumber, R.A. (1966) Factors influencing population levels of *Scolypopa australis* Walker (Hemiptera-Homoptera: Ricaniidae) in New Zealand. *New Zealand journal of science* 9, 336-356.

Cumber, R.A. (1967) Factors influencing egg survival of *Scolypopa australis* Walker (Hemiptera-Homoptera: Ricaniidae) in the Sydney area (N.S.W., Australia). *New Zealand journal of science* 10, 639-643.

Dietz, L.L. (1981) Passionvine hopper, *Scolypopa australis* (Walker), life cycle. *DSIR information series*, 105/35.

DSIR, Entomology Division, file BC 1/4.

English, K.M.I. (1965) A lepidopterous parasite of *Scolypopa australis* Walk. (Hem., Ricaniidae). *Journal of the Entomological Society of Australia (N.S.W.)* 2, 63.

Entomology Division, DSIR (1982) Annual report, 61.

Fletcher, M.J. (1978) The taxonomy, reproduction and development of the fulgoroid homopterans *Scolypopa australis* (Walker) (Ricaniidae) and *Kallitambinia australis* Muir (Tropiduchidae). Ph.D. thesis, University of Sydney, Australia. 208 pp.

Gerard, P.J. (1985) The ecology of *Scolypopa australis* and its parasite *Centrodora scolypopae*. D. Phil. thesis, University of Waikato, Hamilton, New Zealand. 257 pp.

Matheson, A.G. (1978) Aspects of the biology of *Scolypopa australis* Walker (Homoptera: Ricaniidae). M.Sc. thesis, University of Waikato, New Zealand. 122 pp.

Palmer-Jones, T. (1947) A recent outbreak of honey poisoning. Part 1. Historical and descriptive. *New Zealand journal of science and technology* 29A, 107-114.

Patterson, C.R. (1947) A recent outbreak of honey poisoning. Part IV. The source of the toxic honey – field observations. *New Zealand journal of science and technology* 29A, 125-129.

Scott, R.R. (1984) Berry-fruit pests. P. 26 in Scott, R.R. (ed.) New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Siew, Y.C. (1960) Some contributions to the biology of *Scolypopa australis* Walker (Homoptera: Ricaniidae). M.Sc. thesis, University of Auckland, New Zealand. 127 pp.

Spiller, P.M.; Wise, K.A.J. (1982) A catalogue (1840-1960) of New Zealand insects and their host plants. *DSIR bulletin* 231, 260pp.

Steven, D. (In press) Entomology and kiwifruit. Pp. 362-412 in Warrington, I.J.; Weston, G.C. (eds) Kiwifruit: science and management. Ray Richards Publishers and the New Zealand Society for Horticultural Science, Auckland, New Zealand.

Tetranychus urticae Koch, two-spotted mite (Acari: Tetranychidae)

W.P. THOMAS and J.T.S. WALKER

Pest Status

The two-spotted mite (Ramsay 1980), also known as two-spotted spider mite, red spider mite or red mite, *Tetranychus urticae* Koch, is cosmopolitan in its distribution and is a widespread pest of many crops.

A mite referred to as *Tetranychus tellarius* L. was reported on host plants in New Zealand as early as 1873 (Thomson 1922). Manson (1967) considers this a mis-spelling for *T. telarius* (L.), now synonomised with *T. urticae*. Smith (1901) reported *T. telarius* on fruit trees in New Zealand, but many early reports of 'red spider' mite on various hosts in this country refer to other mite species and the situation remains confused (Manson 1967). Several closely related tetranychid species occur on the same hosts in New Zealand and *Panonychus ulmi* (Koch) (Chapter 38) is often associated with *T. urticae* on rosaceous hosts.

The most extensive host plant list for two-spotted mite in New Zealand is that provided by Manson (1987), but many authors discuss this pest in relation to specific cropping systems such as greenhouse, berryfruit, orchard, or field crops. The interactions of *T. urticae* and predators on some specific crops are dealt with by authors in Helle & Sabelis (1985).

Collyer (1976a) provides a brief account of the identification, damage, symptoms and life history of two-spotted mite in New Zealand. Temperature thresholds and intrinsic rate of increase have been determined by Laing (1969) and in New Zealand by Gunson (1984) and Butcher (1986).

Two-spotted mite passes through five to seven generations on field hosts during the summer months. The clear, spherical eggs, normally deposited on the underside of host plant leaves, hatch into six-legged larvae which later moult to become eight-legged, two-spotted, protonymphs, deutonymphs and adults. Adults tend to aggregate and produce an open canopy of webbing under which colonies live. In the more southern regions of New Zealand, diapausing adult females alone survive the winter, often in aggregations. In the north and central parts of the country, part or all of the two-spotted mite population continues to feed and develop through the winter.

Two-spotted mite causes serious feeding damage to host plants by sucking out the cell contents of leaves, causing the cells to collapse and die. Low infestations cause speckling of leaves but at high population densities this mite may cause leaf browning and premature leaf abscission. Marked differences in susceptibility are exhibited by different host plants, but serious leaf damage leads to reduced plant vigour and smaller fruit (Collyer 1976a). Gunson (1984) showed that certain strawberry cultivars are resistant to two-spotted mite attack, while others are relatively susceptible; age of strawberry plants is also important. The nutrient state of host plants, particularly foliage nitrogen content, influences population development (Suski & Badowska 1975).

As with other phytophagous mites, two-spotted mite outbreaks are often induced by the use of broad-spectrum pesticides, such as synthetic pyrethroids, which cause mortality of natural enemies (Chapman & Penman 1979, Wong & Chapman 1979). A further major problem has been the repeated development of resistance to chemicals among phytophagous mite populations, first reported for two-spotted mite in New Zealand by Ballantyne & Harris (1967). As a result, integrated pest management is now used in a number of crops in New Zealand (Charles *et al.* 1985, Martin *et al.* 1984, Penman *et al.* 1979).

Background

A wide range of predators of two-spotted mite is known (see Helle & Sabelis 1985). In New Zealand, these include mites, especially the Phytoseiidae and Stigmaeidae, and species of the insect families Coccinellidae, Thripidae, Miridae, Hemerobiidae and Cecidomyiidae.

Members of the Phytoseiidae are efficient predators of phytophagous mites (Collyer 1964, 1982, Huffaker *et al.* 1970). In New Zealand, this family includes several predators of two-spotted mite, the main ones being *Typhlodromus caudiglans* Schuster, *Amblyseius cucumeris* (Oudemans), *Amblyseius longispinosus* Evans, *Metaseiulus occidentalis* (Nesbitt) and *Typhlodromus pyri* Scheuten. *Stethorus bifidus* Kapur (Coccinellidae) is recognised by Collyer (1964) as the only important coccinellid predator of mites in New Zealand and this species has had a major influence on two-spotted mite control in berryfruit crops (Charles *et al.* 1988b). Chazeau (1979) recognised three species from New Zealand, but these have not been distinguished in recent integrated mite control studies. In Australia, *Stethorus* spp. are also important in the control of two-spotted mite (Field 1979, Readshaw 1975a).

Other predacious species, including the mirid *Sejanus albisignata* (Knight), the cecidomyid *Arthrocnodax* sp., the anthocorid *Cardiastethus* sp., and the thysanopteran *Xylaplothrips* sp., reported as predators by Collyer (1964, 1976b), are probably of less importance than *Stethorus* sp. in this country. Butcher (1986) has shown a species of the family Phalangiidae (harvestmen) is of importance in two-spotted mite control on strawberries. All of these predacious insect species were probably accidentally introduced.

Phytoseiid mites are often associated with two-spotted mite populations on unsprayed host plants but they occur also in sprayed crops that have had long term exposure to pesticides (Hoyt 1969). Huffaker & Kennett (1953) noted that field populations of *Metaseiulus occidentalis* (Nesbitt) in California were tolerant to the organophosphorus insecticide parathion. Similar organophosphate chemical resistance was found in *Neoseiulus fallacis* (Garman) (Croft & Nelson 1972).

Phytoseiid mite resistance to chemicals is now well documented and is reviewed by Croft & Brown (1975). The development of resistance by phytoseiid mites to broad-spectrum insecticides and some fungicides has enabled their use in the biological control of phytophagous mites under intensive pesticide pressure (Hoyt 1969, McMurtry *et al.* 1970).

The decision to augment the fauna predacious on phytophagous mites in New Zealand was taken by Entomology Division, DSIR, in 1965.

Importation, Releases and Recoveries

Predatory insects

Information on introductions is based on unpublished reports by P. Insley and E. Collyer (DSIR files). The introduction of beneficial insects for attempted phytophagous mite control began in 1965 with the importation of *Blepharidopterus angulatus* (Fallén) (Hemiptera: Miridae) and *Anthocoris nemorum* (L.) (Hemiptera: Anthocoridae) from East Malling Research Station, England, and *Hyaliodes harti* Knight (Miridae) and *Anthocoris musculus* (Say) (Anthocoridae) from Nova Scotia, Canada. Details of the importations, releases and recoveries of these general mite predators are dealt with in Chapter 38.

Predatory mites

Phytoseiulus persimilis Athias-Henriot (Acari: Phytoseiidae)

This predatory mite was introduced from Chile to Europe in the late 1950s and was used to control two-spotted mite (Hussey *et al.* 1965) in greenhouses. It is now believed to be indigenous to the Mediterranean region including the south of France (McMurtry 1982). As a result of this success, *P. persimilis* was introduced into New Zealand by K. Harrow of the Plant Diseases Division, DSIR, in 1967 (Walker *et al.* 1981). According to Harrow (pers.

comm.), about 50 active stages were received from staff at the Glasshouse Crops Research Institute, Littlehampton, England. These were mass-reared on two-spotted mite, primarily for distribution to greenhouse growers. Walker *et al.* (1981) suggested that some difficulties were encountered by growers in continuously maintaining populations and the programme declined.

Virtually all stocks of *P. persimilis* were transferred to the Ministry of Agriculture and Fisheries, Christchurch (B. Brandenberg) in 1969 (DSIR files) and local distribution continued there. *P. persimilis* populations, although difficult to maintain continuously in greenhouses, established outdoors in Canterbury near greenhouses (DSIR files, Walker *et al.* 1981). Cultures were established at the Levin Horticultural Research Centre in 1974 from Christchurch populations. Although these cultures were initially identified by E. Collyer as *Phytoseiulus macropilis* (Banks), this determination is considered by G. Ramsay (pers. comm.) to be in error. This strain remained in greenhouse use for a number of years and may have become established in the field more widely than was recognised at the time.

In 1977, C.H. Wearing and F.A. Gunson imported an outdoor 'strain' of *P. persimilis* from Antibes, southern France. This field 'strain' was mass-reared in Auckland and distributed for release (Gunson DSIR files) in 1978 to various locations where establishment and a reduction of two-spotted mite infestations was achieved (Walker *et al.* 1981). It could not be confirmed that this impact was caused by the introduced field 'strain'. Widespread recoveries of *P. persimilis* suggested that field establishment had also occurred from the earlier introductions in the 1960s. The field 'strain' has been reared continuously by Entomology Division, DSIR at Auckland, and has been used as the basis for integrated control programmes for two-spotted mite in greenhouse crops (Martin *et al.* 1984), berryfruit (Charles *et al.* 1988b, Workman 1986) and kiwifruit (Charles *et al.* 1988a) in New Zealand.

P. persimilis field populations have established successfully from early releases made in Auckland, Hawke's Bay, Nelson and Canterbury, but in South Canterbury and Central Otago, populations which establish in summer apparently do not survive winter conditions. Excellent progress for the control of two-spotted mite with *P. persimilis* has been achieved in those cropping systems in New Zealand where compatible pesticide programmes are in place. *P. persimilis* is resistant to azinphos-methyl (Bryham 1985) and phosmet (Workman & Martin 1987), but further research is required to assess the toxicity of a range of pesticides.

Phytoseiulus persimilis was first reported in Australia by Goodwin & Schicka (1979). A shipment of 1,000 field-collected adults from Canterbury was forwarded to D.A. Raworth, Agriculture Canada, in February 1986.

Neoseiulus (= *Amblyseius*) *fallacis* (Garman) (Acari: Phytoseiidae)

Through B.A. Croft, an organophosphorus-resistant strain of *N. fallacis* (Croft & Nelson 1972) was forwarded from Michigan, U.S.A. to Nelson in 1972 (E. Collyer pers. comm.) but no mites survived. Three additional consignments of this strain were sent to Lincoln in October 1973 and one more in 1975 (Thomas & Chapman 1978). The strain was successfully reared under quarantine conditions on two-spotted mite on bean leaves, and later, cultures were established on bean plants. Many thousands of individuals were released in Appleby Research Orchard, Nelson, over three seasons (1973-1976) but the species failed to establish on apple trees there. During the same period, releases were also made at Loburn and Lincoln (Canterbury), Hope (Nelson), Hastings, Waimate and Central Otago. Establishment was achieved in some localities (Loburn, Lincoln and Hastings) and two-spotted mite was reduced at sites in Canterbury where the predator was released (Thomas & Chapman 1978). Ground cover vegetation harbouring two-spotted mite was shown to be important in the survival of *N. fallacis* in New Zealand as reported for North America by Croft & McGroarty (1977). In the study of Penman & Chapman (1980), within-season control of phytophagous mites was achieved from direct releases of *N. fallacis* onto apple trees, but subsequent overwintering

mortality of this predator was of concern. Population increase was too slow in spring to prevent mite damage.

Establishment of this species was also achieved in Central Otago from 1975 on prey populations of several mite species, including two-spotted mite (G.F. McLaren pers. comm.). Mass-propagation and release programmes, based on those of Field *et al.* (1979) for *Metaseiulus occidentalis*, were conducted in Hawke's Bay, Nelson and Canterbury during 1980-1981 (DSIR files). However, these were unsuccessful in achieving widespread establishment of *N. fallacis* in apple orchards in these regions.

Prior to *P. persimilis* field establishment in Canterbury berryfruit gardens, *N. fallacis* had become dominant in suppressing two-spotted mite populations during the 1980-85 period. However, this species has now been largely displaced by *P. persimilis*. This *N. fallacis* 'strain' was sent to Australia in 1976 (DSIR files), and on request was shipped to Japan with *M. occidentalis* in 1986.

Metaseiulus occidentalis (Nesbitt) (Acari: Phytoseiidae)

An organophosphorus-resistant strain of this predatory mite was supplied in 1976 by J.L. Readshaw, Commonwealth Scientific and Industrial Research Organisation, Australia, following its successful introduction into that country from North America in 1972 (Readshaw 1975b) and widespread distribution (Field 1979). This species was present in New Zealand prior to release of the organophosphorus-resistant strain (Collyer 1964).

In New Zealand, *M. occidentalis* was initially reared in a similar way to *N. fallacis* and later was laboratory-reared in Auckland (DSIR files). This resistant strain was released in Nelson, Hastings, Waimate, Central Otago and Lincoln and became established in Central Otago, Canterbury and at Hope, Nelson (DSIR files). In Canterbury and Central Otago the imported strain has persisted in orchards at very low levels (Thomas & G.F. McLaren unpublished). Initial control of two-spotted mite on apple trees at Hope was encouraging (DSIR files). However, although within-season mite control of two-spotted mite was obtained on release trees following release, this programme has not achieved the same degree of successful control of two-spotted mite in New Zealand as that reported in Australia (Readshaw 1975b).

Evaluation

The development of pesticide resistance in several species of the Phytoseiidae (Penman *et al.* 1979) has enabled their use in integrated pest management programmes in various horticultural crops in New Zealand (such as berryfruit), and in greenhouses. *P. persimilis* has been successfully established and provides control of two-spotted mite in various crops (Charles 1988, Martin *et al.* 1984, Workman 1986). This is the most successful of the phytoseiids introduced to New Zealand for control of two-spotted mite.

In Canterbury, populations of *N. fallacis* and *M. occidentalis* established in berryfruit crops have now been largely replaced by the more aggressive and persistent *P. persimilis* (Thomas unpublished). It is possible that the field populations of *P. persimilis* will eventually adapt to cooler conditions to become permanently established in the more southern regions of New Zealand. Annual releases of *P. persimilis* for two-spotted mite control in berryfruit and kiwifruit are presently recommended (Charles *et al.* 1988). Similar procedures are followed in southern California (McMurtry *et al.* 1978).

N. fallacis and *M. occidentalis* have become established in some regions of New Zealand, especially in the south. However, they are not providing the high level of phytophagous mite control reported from North America (Helle & Sabelis 1985, Hislop & Prokopy 1978/1979).

Conclusions

The importation of phytoseiid mite species into New Zealand, especially *P. persimilis* from France, has been very beneficial in achieving two-spotted mite control in various crops using integrated pest management programmes. Development of resistance to pesticides by the predators has been essential for their success. Selection of *P. persimilis* for resistance to synthetic pyrethroids is in progress (N.A. Markwick pers. comm.) in an attempt to extend the range of situations in which this predator can be used.

There is no apparent need for additional importations of beneficial predatory species at present. In the absence of pesticides, native and introduced phytoseiids, including *P. persimilis*, *Stethorus* spp., mirids and other predators provide adequate control of two-spotted mite on most host plants.

Literature Cited

Ballantyne, G.; Harrison, R.A. (1967) Resistance to organophosphates in New Zealand strains of the two-spotted spider mite, *Tetranychus telarius* (L.). *New Zealand journal of science* 10, 915-917.

Bryham, M.L. (1985) The toxicity of pesticides to the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseiidae) and its prey *Tetranychus urticae* Koch (Acarina: Tetranychidae). M.Sc. thesis, University of Auckland, Auckland, 82 pp.

Butcher, M. (1986) Aspects of the ecology of a strawberry crop with special reference to two-spotted spider mite (Tetranychidae: Acari). Ph.D. thesis, University of Canterbury, Lincoln College, 175 pp.

Chapman, R.B.; Penman, D.R. (1979) Toxicity of synthetic pyrethroid insecticides to phytophagous orchard mites. *Proceedings of the 32nd New Zealand Weed and Pest Control Conference*, 240-244.

Charles, J.G. (1988) Using *Phytoseiulus* to control two-spotted mites in strawberries. *Proceedings of the 41st New Zealand Weed and Pest Control Conference*, 202-206.

Charles, J.G.; Collyer, E.; White, V. (1985) Integrated control of *Tetranychus urticae* with *Phytoseiulus persimilis* and *Stethorus bifidus* in commercial raspberry gardens. *New Zealand journal of experimental agriculture* 13, 385-393.

Charles, J.G.; Martin, N.A.; Workman, P.J. (1988a) DSIR releases one million predator mites. *New Zealand kiwifruit* July 1988, 17.

Charles, J.G.; Thomas, W.P.; Workman, P.J. (1988b) Control of two-spotted mite *Tetranychus urticae* Koch in New Zealand berryfruit. *Proceedings 18th International Congress of Entomology, Vancouver, Canada*, 326.

Chazeau, J. (1979) Mise au point sur le genre *Stethorus* en Océanie et description de deux espèces nouvelles de Mélanésie (Col. Coccinellidae) *Entomophaga* 24, 295-303.

Collyer, E. (1964) Phytophagous mites and their predators in New Zealand orchards. *New Zealand journal of agricultural research* 7, 551-568.

Collyer, E. (1976a) Two-spotted mite, *Tetranychus urticae* Koch, life cycle. *DSIR Information Series* 105/24, 2 pp.

Collyer, E. (1976b) Integrated control of apple pests in New Zealand 6. Incidence of European red mite, *Panonychus ulmi* (Koch), and its predators. *New Zealand journal of zoology* 3, 39-50.

Collyer, E. (1982) The Phytoseiidae of New Zealand (Acarina) 1. The genera *Typhlodromus* and *Amblyseius* – keys and new species. *New Zealand journal of zoology* 9, 185-206.

Croft, B.A.; Brown, A.W.A. (1975) Responses of arthropod natural enemies to insecticides. *Annual review of entomology* 20, 285-335.

Croft, B.A.; McGroarty, D.L. (1977) The role of *Amblyseius fallacis* (Acarina: Phytoseiidae) in Michigan apple orchards. *Michigan State Agriculture Experiment Station research report* 333, 21 pp.

Croft, B.A.; Nelson, E.E. (1972) Toxicity of apple orchard pesticides to Michigan populations of *Amblyseius fallacis*. *Environmental entomology* 1, 576-579.

DSIR, Entomology Division, file BC 1/4.

Field, R.P. (1979) Integrated pest control in Victorian peach orchards: the role of *Stethorus* spp. (Coleoptera: Coccinellidae). *Journal of the Australian Entomological Society* 18, 315-322.

Field, R.P.; Webster, W.J.; Morris, D.S. (1979) Mass rearing *Typhlodromus occidentalis* Nesbitt (Acarina: Phytoseiidae) for release in orchards. *Journal of the Australian Entomological Society* 18, 213-215.

Goodwin, S.; Schicka, E. (1979) Discovery of the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseiidae) in Australia. *Journal of the Australian Entomological Society* 18, 304.

Gunson, F.A. (1984) Aspects of resistance to *Tetranychus urticae* in New Zealand strawberry cultivars. Ph.D. Thesis, University of Auckland, Auckland, New Zealand. 172 pp.

Helle, W.; Sabelis, M.W. (eds) (1985) Spider mites: their biology, natural enemies and control. In world crop pests, vol. 1B. Elsevier, Amsterdam. 458 pp.

Hislop, R.G.; Prokopy, R.J. (1978/1979) Integrated management of phytophagous mites in Massachusetts (USA) apple orchards. 1. Foliage inhabiting mite complexes in commercial and abandoned orchards. *Protection ecology* 1, 279-290.

Hoyt, S.C. (1969) Integrated chemical control of insects and biological control of mites on apple in Washington. *Journal of economic entomology* 62, 74-86.

Huffaker, G.B.; Kennett, C.E. (1953) Differential tolerance to parathion in two *Typhlodromus* predatory on cyclamen mites. *Journal of economic entomology* 46, 707-708.

Huffaker, G.B.; van de Vrie, M.; McMurtry, J.A. (1970) Ecology of tetranychid mites and their natural enemies: A review. II. Tetranychid populations and their possible control by predators: An evaluation. *Hilgardia* 40, 391-458.

Hussey, N.W.; Parr, W.I.; Gould, H.J. (1965) Observations on the control of *Tetranychus urticae* Koch on cucumbers by the predatory mite *Phytoseiulus riegeli* Dosse. *Entomologia experimentalis et applicata* 8, 271-281.

Laing, J.E. (1969) Life history and life table of *Tetranychus urticae* Koch. *Acarologia* 11, 32-42.

Manson, D.C.M. (1967) The spider mite family Tetranychidae in New Zealand. II – the genus *Tetranychus*. *Acarologia* 9, 581-597.

Manson, D.C.M. (1987). A list of New Zealand mites and their host plants. *DSIR Bulletin* 240, 63 pp.

Martin, N.A.; Workman, P.J.; Burgess, E.P.; Wearing, C.H. (1984) Integrated pest control in greenhouse crops. *Proceedings of 37th New Zealand Weed and Pest Control Conference*, 253-261.

McMurtry, J.A. (1982) The use of phytoseiids for biological control: progress and future prospects. Pp. 23-48 in Hoy, M.A. (ed) Recent advances in knowledge of the Phytoseiidae. Division of Agricultural Sciences, University of California, U.S.A. Publication 3284.

Tetranychid enemies: their biological characters and the impact of spray practices. *Hilgardia* 40, 331-390.

McMurtry, J.A.; Oatman, E.R.; Phillips, D.A.; Wood, C.W. (1978) Establishment of *Phytoseiulus persimilis* (Acari: Phytoseiidae) in Southern California. *Entomophaga* 23, 175-179.

Penman, D.R.; Chapman, R.B. (1980) Integrated contol of apple pests in New Zealand. 17. Relationships of *Amblyseius fallacis* to phytophagous mites in an apple orchard. *New Zealand journal of zoology* 7, 281-287.

Penman, D.R.; Wearing , C.H.; Collyer, E.; Thomas, W.P. (1979) The role of insecticide-resistant phytoseiids in integrated mite control in New Zealand. *Recent advances in acarology* 1, 59-69.

Ramsay, G.W. (1980) Common and scientific names of New Zealand mites. *DSIR Information series* 139, 32 pp.

Readshaw, J.L. (1971) An ecological approach to the control of mites in Australian orchards. *Journal of the Australian Institute of Agricultural Science* 37, 226-230.

Readshaw, J.L. (1975a) The ecology of tetranychid mites in Australian orchards. *Journal of applied ecology* 12, 473-495.

Readshaw, J.L. (1975b) Biological control of orchard mites in Australia using an insecticide-resistant predator. *Journal of the Australian Institute of Agricultural Science* 38, 308-309.

Smith, W.W. (1901) On mites attacking beetles and moths. *Transactions of the New Zealand Institute* 34, 199-201.

Suski, Z.W.; Badowska, T. (1975) Effect of the host plant nutrition on the population of the two spotted spider mite, *Tetranychus urticae* Koch (Acarina, Tetranychidae). *Ekologia Polska* 23, 185-209.

Thomas, W.P.; Chapman, L.M. (1978) Integrated control of apple pests in New Zealand. 15. Introduction of two predacious phytoseiid mites. *Proceedings of the 31st New Zealand Weed and Pest Control Conference*, 236-243.

Thomson, G.M. (1922) The naturalisation of animals and plants in New Zealand. Cambridge University Press, Cambridge, U.K., 607 p.

Walker, J.T.S.; Wearing, C.H.; Proffitt, C.; Charles, J.G. (1981) Predator for two-spotted spider mite establishes in orchards. *The orchardist of New Zealand* 54, 340.

Workman, P.J. (1986) Integrated control of two-spotted mite on strawberry runner beds. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 162-165.

Workman, P.J.; Martin, N.A. (1987) Toxicity of two pesticides to *Phytoseiulus persimilis*. *Proceedings of the 40th New Zealand Weed and Pest Control Conference*, 108-111.

Wong, S.W.; Chapman, R.B. (1979) Toxicity of synthetic pyrethroid insecticides to predaceous phytoseiid mites and their prey. *Australian journal of agricultural research* 30, 492-501.

Trialeurodes vaporariorum (Westwood), greenhouse whitefly (Homoptera: Aleyrodidae)

N.A. MARTIN

Pest Status

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), is a serious pest of greenhouse and outdoor crops. This species is found in most parts of the world (Mound & Halsey 1978) though it reached China and Japan only during the 1970s (Xu 1982, Yano 1981). It has been in New Zealand since at least 1889 (Dumbleton 1957) and was reported to be a pest of tomatoes by Muggeridge (1931). Greenhouse whitefly is now the most abundant of the several exotic species of whitefly in New Zealand. This insect has a wide host range (Mound & Halsey 1978) and is a serious problem on greenhouse tomatoes and cucumbers (where sooty moulds often occur) and in New Zealand on the outdoor crop, tamarillo, *Cyphomandra betacea* (Cav.) Sendtner (Solanaceae). In many parts of New Zealand, greenhouse whitefly can survive outdoors all the year and it readily moves between greenhouses and outdoors. It is sometimes confused with the cabbage whitefly *Aleyrodes proletella* (L.) (Aleyrodidae) which is the whitefly pest on Brassicaceae in New Zealand, and with a common mothfly, *Psychoda spatulata* Satchell (Diptera: Psychodidae).

The biology of greenhouse whitefly has most recently been summarised by Vet *et al.* (1980). Adults feed and lay eggs on the underside of leaves where the four scale-like nymphal stages develop. The eggs and puparia are tolerant to most pesticides. This, and the need to get good spray coverage on the underside of the leaves, make it difficult to control by even modern pesticides. Overseas, greenhouse whitefly has become resistant to at least 11 pesticides (Elhag & Horn 1983, Georghiou 1981).

Background

Encarsia formosa Gahan (Hymenoptera: Aphelinidae), the best known parasitoid of greenhouse whitefly, was described in 1924 and since 1927 has been used to control the pest in greenhouse crops in England and many other parts of the world (Hussey 1985). Of the other known parasitoids of greenhouse whitefly (Mound & Halsey 1978, Vet *et al.* 1980), *Encarsia pergandiella* Howard was reared from greenhouse whitefly collected in Auckland, New Zealand in 1975 and 1981 by J.S. Timlin and Martin respectively. The identity of the 1981 specimens was confirmed in 1983 by G. Viggiani, Instituto di Entomologia Agraria, Dell' Università di Napoli, Portici, Italy. Blank *et al.* (1986) found up to 30% of over-wintering whitefly pupae on tamarillo parasitised with *Encarsia* (probably *pergandiella*). Male as well as female *E. pergandiella* are readily found whereas male *E. formosa* are uncommon. The indigenous species of whitefly can be heavily parasitised (Dumbleton 1957) but none of these parasitoids is known from greenhouse whitefly.

The fungal pathogen, *Verticillium lecanii* has been found only twice during the last 12 years on greenhouse whitefly in Auckland greenhouses (Martin unpublished data). On both occasions it appeared in the autumn while the greenhouses were warm and humid. Strains of this pathogen have been used in Europe for whitefly and aphid control.

Aschersonia aleyrodis, another fungal pathogen currently being developed overseas for whitefly control (Fransen 1987), has not been found in New Zealand. It has the advantage of requiring only a very short period of high humidity for infection of its host.

Importations, Releases and Recoveries

There were four attempts to import and establish *E. formosa* from the Institute of Entomology, England, (Muggeridge 1931, 1933, 1934, Tonnoir 1937). Three boxes of *E. formosa* were sent in cool storage (4-6°C) and received on 8 January 1931, but no parasitoids emerged. A second consignment on living plants in boxes arrived in January 1932 but this also failed (Tonnoir 1937). Twenty wasps emerged from the third consignment sent in cool storage via Panama (Tonnoir 1937). The parasitoids, which arrived on 5 January 1933, failed to establish in a greenhouse in Palmerston North. Later in 1933 the fourth shipment of *E. formosa* was received and a small colony was established in a greenhouse. They were reared through the winter months and a small quantity of parasitoids were distributed to tomato growers in late spring (Muggeridge 1934). One greenhouse grower reported no further problems with whitefly. During 1934-35 small quantities of *E. formosa* were supplied to greenhouse growers. The parasitoid overwintered in Hawke's Bay and spread north to greenhouses and fields around Hastings. Whitefly was reported to be far less prevalent in Hawke's Bay than previously (Muggeridge 1935). The parasitoid continued to be reared during 1935-36 and was distributed on request. Muggeridge (1936a, 1936b) also mentions that when given time to establish, *E. formosa* proves a thoroughly effective check to the whitefly.

Evaluation

Hudson (1946), in an article on growing chrysanthemums, mentions that *E. formosa* was reported to be controlling the pest and Valentine (1963) reported that *E. formosa* was established in the North Island and in Nelson.

It appears that New Zealand growers were supplied with *E. formosa* for several years and that after this they relied on the parasitoid to appear naturally in the greenhouse on each new crop from populations surviving outside. In contrast, a large colony in England was kept going until 1949, and growers acquired parasitoids for each crop (Hussey 1985). In the 1950s and 1960s whitefly were mainly controlled with new pesticides such as DDT and maldison, although there are occasional reports of *E. formosa* appearing on New Zealand greenhouse tomato crops. During this period the parasitoid appears to have survived outdoors. In 1976, R.A. Cumber in a letter (DSIR files) referred to the parasitoid working field populations in March and mentioned that it did little to control outside populations until rather late in the season. He also mentioned (R.A. Cumber pers. comm.) that whitefly were more numerous in the 1970s and that *E. formosa* was less common. E.W. Valentine (DSIR files) commented that *E. pergandiella* had become more common than *E. formosa* both outdoors and in greenhouses.

The New Zealand strain of *E. formosa* has now been separated from the European strain for more than fifty years, and changes in its biology may have occurred which could affect its ability to control whitefly. However, while the New Zealand strain survived many years outdoors and the European strain survived in hot-houses (Hussey 1985), no differences between the strains have yet been detected (van Vianen & van Lenteren 1982, Walker 1983). Nevertheless, one feature noticed in the New Zealand strain has not been reported from elsewhere. *E. formosa* puparia are usually black, but a small proportion of those in New Zealand are either only partially melanised or remain unmelanised. This feature could tend to cause parasitism to be slightly underestimated.

Because of problems of pesticide resistance in greenhouse pests, integrated pest management systems were developed in England in the late 1960s and early 1970s. They used *E. formosa* for whitefly control and relied on introducing the parasitoid several times into each new crop. In 1972/73 *E. formosa* was sent from Auckland to Christchurch and was used to control whitefly in several greenhouse crops under the supervision of J. Ballinger, Department of Agriculture. In 1973 D.J. Dennis, Department of Agriculture, Levin Horticultural Research Centre, Levin, established a colony of *E. formosa* from parasitoids collected in

Auckland. The colony was supplemented with parasitoids from Christchurch in 1976 and 1977. This colony was kept going until 1980. During this time parasitoids were supplied to some greenhouse growers. In the last year, a second species of *Encarsia* may have been present in the colony.

In 1980, a colony of *E. formosa* was established at the DSIR Mount Albert Research Centre, Auckland with parasitoids from Lincoln Research Centre greenhouses which had originally been supplied from the Levin colony. During the first two years *E. pergandiella* also established itself in the Auckland colony. *E. pergandiella* lays fertilised eggs in greenhouse whitefly larvae, and these develop into female wasps. Unmated females parasitise pupae of *Encarsia* species, including their own species and *E. formosa*. These develop into males. While mixed *E. formosa* and *E. pergandiella* controlled whitefly in a commercial greenhouse tomato crop (Martin unpublished), the use of *Encarsia* species that produce males is wasteful. This is because when female parasitoids emerge from parasitised whitefly pupae placed in a commercial greenhouse, the first females to emerge parasitise the unemerged parasitoid pupae so that the yield of effective female parasitoids is substantially reduced. In mixed colonies, *E. pergandiella* females start emerging before *E. formosa* and so gradually replace *E. formosa*. Precautions are now taken to keep *E. pergandiella* out of the *E. formosa* colony at Auckland.

Conclusions

Since 1981, integrated pest management (IPM) systems have been developed for several greenhouse crops in New Zealand (Martin 1987). Some of these rely on the introduction of *E. formosa* at the appropriate stage of the crop. For these IPM systems to work, the growers must be able to buy the parasitoids when they need them. Commercial production of *E. formosa* is planned.

Acknowledgements

D.J. Dennis, Ministry of Agriculture and Fisheries, Levin for details of the Levin colony; P.J. Cameron, C.F. Morales and P. Workman for assistance and constructive comments.

Literature Cited

Blank, R.H.; Balgrove, M.J.; Waller, J.E. (1986) Screening chemicals to control greenhouse whitefly on tamarillo. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 148-152.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1957) The New Zealand Aleyrodidae (Hemiptera: Homoptera). *Pacific science* 11, 141-160.

Elhag, E.A.; Horn, D.J. (1983) Resistance of greenhouse whitefly (Homoptera : Aleyrodidae) to insecticides in selected Ohio greenhouses. *Journal of economic entomology* 76, 945-948.

Fransen, J.J. (1987) Control of greenhouse whitefly, *Trialeurodes vaporariorum*, by the fungus *Aschersonia aleyrodis*. Pp. 57-61 in Nedstam, B.; Stengard Hansen, L.; Lenteren, J.C. van (eds) Working group 'Integrated control in glasshouses'. EPRS/WPRS, Budapest (Hungary) 26-30.04.87, *WPRS Bulletin*.

Georghiou, G.P. (1981) The occurrence of resistance to pesticides in arthropods, an index of cases reported through 1980. Food and Agriculture Organisation, Rome, Italy. 172 pp.

Hudson, J.P. (1946) Combating pests and diseases of chrysanthemums. *New Zealand journal of agriculture* 73, 91-94.

Hussey, N.W. (1985) History of biological control in protected culture 1.1 Western Europe. Pp. 11-22 in Hussey, N.W.; Scopes, N. (eds) Biological pest control, the glasshouse experience. Blandford Press, Poole, Dorset, England.

Martin, N.A. (1987) Progress towards integrated pest management for greenhouse crops in New Zealand. Pp. 111-115 in Nedstam, B.; Stengard Hansen, L.; Lenteren, J.C. van (eds) Working group 'Integrated control in glasshouses'. EPRS/WPRS, Budapest (Hungary) 26-30.04.87, *WPRS Bulletin*.

Mound, L.A.; Halsey, S.H. (1978) Whitefly of the world. J. Wiley and Sons, Chichester, England, 340 pp.

Muggeridge, J. (1931) Report for Entomology Section. *Report of the Department of Agriculture, 1930-31*, 46.
Muggeridge, J. (1933) Report for Entomology Section. *Report of the Department of Agriculture 1932-33*, 47-49.
Muggeridge, J. (1934) Report for Entomology Section. *Report of the Department of Agriculture 1933-34*, 42-43.
Muggeridge, J. (1935) Report for Entomology Section. *Report of the Department of Agriculture 1934-35*, 47.
Muggeridge, J. (1936a) Report for Entomology Section. *Report of the Department of Agriculture 1935-36*, 49-50.
Muggeridge, J. (1936b) Report for Entomology Section. *Department of Scientific and Industrial Research. Tenth annual report*, 25-27.
Tonnoir, A.L. (1937) The biological control of the greenhouse whitefly in Australia. *Journal of the Council for Scientific and Industrial Research, Australia* 10, 87-100.
Valentine, E.W. (1963) New records of hymenopterous parasites of Homoptera in New Zealand. *New Zealand journal of science* 6, 6-13.
Vet, L.E.M.; Lenteren, J.C. van; Woets, J. (1980) The parasite host relationship between *Encarsia formosa* (Hymenoptera: Aphelinidae) and *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae) IX. A review of the biological control of the greenhouse whitefly with suggestions for future research. *Zeitschrift für angewandte Entomologie* 90, 26-51.
Vianen, A. van; Lenteren, J.C. van (1982) Increasing the number of ovarioles of *Encarsia formosa*: a possibility to improve the parasite for biological control of the greenhouse whitefly *Trialeurodes vaporariorum. Mededelingen van de Faculteit Landbouwwetenschappen Rijksuniversiteit Gent* 47, 523-531.
Walker, P.W. (1983) Developing pesticide resistant strains of *Encarsia formosa*: *Sting. Newsletter of biological control in greenhouses* 6, 16.
Xu Ru-mei (1982) Research on greenhouse whiteflies and its biological control in China. *Sting. Newsletter on biological control in greenhouses* 5, 13.
Yano, J. (1981) Greenhouse whitefly *Trialeurodes vaporariorum* (Westw.) (Hom., Aleyrodidae) in Japan and possibilities for its control by *Encarsia formosa* Gahan (Hym., Aphelinidae). *Zeitschrift für angewandte Entomologie* 92, 364-370.

PART 4.

Forestry Pests

The first attempts to biologically control a forestry insect pest in New Zealand were made in 1905 when T.W. Kirk, of the then Department of Agriculture, introduced and re-distributed coccinellids to control *Eriococcus coriaceus* Maskell (Chapter 45). This was an auspicious start because the efficient and rapid control of the gum tree scale by *Rhyzobius ventralis* (Erichson) has been rightly hailed as one of the best successes in the biological control of forest insect pests.

In the 1920s successful projects were initiated at the Cawthron Institute and the associated Forest Biological Research Station to control *Asterodiaspis* spp. and *Sirex noctilio* F. The work on *S. noctilio* was continued at the Forest Research Institute, Rotorua (FRI) throughout the 1950s and 1960s and has been the largest biological control programme directed against a forest pest in New Zealand.

During the late 1920s and the early 1930s D. Miller, firstly with the Department of Agriculture, and then along with A.F. Clark at the Cawthron Institute, introduced an egg parasitoid which successfully controlled *Gonipterus scutellatus* Gyllenhal on *Eucalyptus* spp. (Chapter 46). Clark was also involved with biological control attempts against *Hylastes ater* (Paykull), *Paropsis charybdis* Stål and *Pineus laevis* (Maskell) (Chapters 47, 49 and 51). In the mid 1930s Miller and E.S. Gourlay received and liberated a parasitoid of *Tuberculatus annulatus* (Hartig) (Chapter 53).

There was no further work on the importation of natural enemies of forest or tree pests until the mid to late 1950s when the FRI and the DSIR undertook projects against *Megastigmus spermotrophus* Wachtl and *Phyllonorycter messaniella* (Zeller) respectively (Chapters 48 and 50).

During the 1950s and 1960s the FRI imported further parasitoids of *Sirex noctilio* and three of them became established. While there is no doubt that these parasitoids have a significant effect on *S. noctilio* populations, the decline in the significance of *S. noctilio* as a pest species is also due in large part to the effects of the parasitic nematode *Deladenus siricidicola* Bedding and to improved silviculture (Chapter 52). The nematode was presumably introduced with its host and was later deliberately spread to forests where it was not known to occur.

In the early 1960s both DSIR and FRI were involved in attempts to introduce parasitoids of *Paropsis charybdis* but it was not until the 1970s that the FRI concentrated efforts against this most serious pest of eucalypts. These have continued until the present and the first tentative successes are reported in Chapter 49.

Of the ten target pests reported on in this section, action against six can be considered successful in the sense that the introduction and/or distribution of natural enemies has resulted in significant control. A further three targets are not presently considered to be of enough significance to warrant more work. The major exception is *Paropsis charybdis* which is still the subject of biological control attempts. The FRI also has a biological control programme against the recently introduced Australian leaf mining sawfly, *Phylacteophaga froggatti* Riek (Pergidae). This species was first found in New Zealand in 1985. Work on its biological control was commenced too late for inclusion in this review.

Asterodiaspis spp., pit scales (Homoptera: Asterolecaniidae)

A.M. FERGUSON

Pest Status

Asterodiaspis spp. scales on oak trees are cosmopolitan. There are three species, *A. variolosa* Ratzeburg, *A. quercicola* (Bouché) and *A. minus* (Lindinger), which are collectively called pit scales. *A. variolosa* is known in New Zealand and in the U.S.A. as the 'golden oak' or 'pustular' scale (Brown & Eads 1965, Gourlay 1935). Pit scales have been known as pests for over 150 years and are thought to be of Asian or European origin. They have since spread to Russia, North and South America (Hanson & Miller 1984), North and South Africa (Brain 1919) and Australia (Wilson 1960).

Scales which formed pits on English oak trees in New Zealand were first noticed at Nelson in about 1881 (Gourlay 1935) and by the early 1920s were common throughout the country (Miller 1925). They were probably accidentally introduced on oaks imported from England by the early European settlers (Gourlay 1935).

Gourlay (1935) recorded English oak *Quercus robur* L. and an unidentified *Quercus* sp. as the hosts for pit scales in New Zealand. *A. quercicola* has recently been recorded on *Q. palustris* Münchhausen for the first time (A.M. Ferguson & L.M. Emms unpublished). Overseas, pit scales have been recorded from at least 12 species of oak (Parr 1940) and from olive trees (Evans 1939).

Oak trees react vigorously to the presence of pit scales and become unsightly because twigs become shorter and thinner, excessively branched, and roughened with pits. Such twigs carry fewer leaves (Parr 1940). The pits resulting from two scales on opposite sides of the tip of a twig can easily coalesce and prove lethal to small twigs (Parr 1940). Affected hosts retain dead leaves throughout the winter and leaf flush can be delayed by up to three weeks in the spring (Johnson & Lyon 1976). The unsightly fungus disease anthracnose is often associated with pit scale in eastern U.S.A. (Johnson & Lyon 1976) but has not been recorded from oaks in New Zealand (S.R. Pennycook pers. comm.).

The severity of scale damage to the host depends upon the vigour and age of the tree and on the position and density of the scales. Twigs, branches and entire trees can be killed if the host is under stress (DSIR files, Miller 1925, Parr 1940). Densities can differ markedly between adjacent trees (Gourlay 1935, Ferguson unpublished). This may be due to differential levels of stress between infested trees, or because pit scale populations, or even species, may have adapted to specific genotypes of oak trees (Edmunds & Alstad 1978). In New Zealand, Gourlay (1935) found that young trees occasionally died but older hosts survived despite extensive injury.

Background

Until recently when L.M. Emms & A.M. Ferguson (unpublished) identified both *Asterodiaspis variolosa* and *A. quercicola* from oaks in New Zealand, there has been confusion over which species of *Asterodiaspis* occur here. In 1922 E.S. Gourlay (DSIR files) referred to the oak scale in New Zealand as *Asterolecanium variolosa* but in the same year R.J. Tillyard called it *Asterolecanium quercicola* (DSIR files). Russell (1941) and Wise (1977) list only *Asterolecanium quercicola* although Wise (pers. comm.) suspected the presence of both species.

There is confusion in the literature regarding the life-history of pit scales, probably caused by the taxonomic difficulties. The life-cycle of *Asterodiaspis* spp. in New Zealand is reported in Gourlay (1935). He stated that there was one generation a year with distinct crawler production from eggs in October, consisting of only females, and from February until May, comprising both sexes. He claimed that two releases of crawlers resulted from differential rates of development of the overwintering adult females (Gourlay 1935) but he may have been dealing with more than one species. The initial number of crawlers which settle on twigs can be considerable but many disappear quickly (Boratynski 1961) because of bird predation, wind and rain (Parr 1940).

Overseas, crawlers are produced virtually continuously throughout the summer and male scales are unknown (Newstead 1903, Podsiadlo 1975, 1986, Parr 1940). In some countries *Asterodiaspis* spp. are ovoviviparous (Parr 1940, Pritchard & Beer 1950, Tsalev & Vulcheva 1963) but, in others, are reported to be oviparous (Brain 1919, Podsiadlo 1975, Yanin 1975).

There are two major cosmopolitan parasitoids of pit scales (Podsiadlo 1986). *Habrolepis dalmanni* (= *dalmani* = *dalmanii*) (Westwood) is recorded from many European countries, U.S.S.R., northern and southern Africa (Annecke & Mynhardt 1970) and North and South America. The second, *Metaphycus asterolecanii* (Mercet) (= *Aphycus variolosus* Mercet), is found in many European countries, Russia and North Africa. These two parasitoids have a significant role in limiting populations of *Asterodiaspis quercicola* and *A. variolosa* in Poland. Podsiadlo (1986) found that the overwintering parasitoid generation of each species destroyed one third of the scales and that the two species were complementary, *H. dalmanni* ovipositing in mature females and *M. asterolecanii* in second instars. In Poland, and apparently in New Zealand (Ferguson unpublished), the summer generation of *H. dalmanni* partly limits the reproduction of the scale. Gonzales & Rojas (1967) also report partial control of pit scale with *H. dalmanni* in Chile.

No pathogens, repellents, or pheromones of pit scales are mentioned in the literature. Pritchard & Beer (1950) did not find any diseases of *A. minus* or *A. quercicola* in California. There is at least one pathogen of *A. variolosa* and its parasitoid in New Zealand, *Trichothecium roseum* (Persoon) Link (L.M. Emms & A.M. Ferguson unpublished).

Overseas, predators of dense pit scale populations include birds (Newstead 1903, Parr 1940), predaceous mites (Podsiadlo 1975, 1986, Pritchard & Beer 1950), and thrips (Pritchard & Beer 1950). A partial catalogue of parasitoids and predators of *Asterodiaspis* spp. has been compiled by Herting (1972). In New Zealand, large numbers of the predatory mite *Hemisarcoptes* sp. were found beneath the test of the scale by Miller (1925) but not by Gourlay (1935). The coccinellid *Orcus chalybeus* (Boisduval) was introduced to attack scale insects (see Chapters 40, 45). It failed to establish in Canterbury despite further introductions from Auckland where it had established and proved useful against *Asterodiaspis* sp. (Miller 1925).

Screening trials with modern insecticides have shown that some chemicals (e.g. diazinon) can control pit scales (Koehler 1964). However, in Christchurch in the early 1920s, spraying with oils was difficult and adjudged to have had no effect (DSIR files). Therefore the introduction of a parasitoid was considered the most practical means of control available for the established trees which were valued for aesthetic and historical reasons and could not all be felled (Gourlay 1935, DSIR files). Gourlay (1935) had detected that turkey oak *Q. cerris* L. and some strains of English oak were immune to scale and suggested that they replace *Q. robur*. These same turkey oaks were uninfested in 1988 despite the presence of pit scale on English oaks in the same stand (Ferguson unpublished).

Importations, Releases and Recoveries

When the importation programme began parasitoids of *Asterodiaspis* spp. were not available from Europe (Tillyard 1926a). The Bureau of Entomology, Washington D.C., was

approached and from 1923 until 1928 supplied eight shipments of *H. dalmanni* in scales on oak twigs collected from Massachusetts. The details of each consignment are shown in Table 44.1. This parthenogenetic insect was the only one then recognised to parasitise pit scales (Nicholls 1933, Tillyard 1926b) although *M. asterolecanii* had been described from oak scales in 1925. In hindsight, *H. dalmanni* was a suitable species because it is now known to attack both pit scale species on oaks in New Zealand (Herting 1972).

Table 44.1 Importations and releases of *Habrolepis dalmanni* into New Zealand. Parasitoid source: *Asterodiaspis*-infested oak twigs from Massachusetts, U.S.A. After Gourlay (1935) and DSIR files.

Date of arrival	Number		Adult release details
	emerged	released	
6 Feb. 1923	62	many died pre-release	insectary and confined to tree outside, Christchurch
16 Feb. 1924	2	2	2 insectary, Nelson
3 Nov. 1924	10	10	10 insectary, Nelson
24, 26 Nov. 1925	458	428	140 insectary, Nelson; 288 field, Nelson
20 Jan. 1926	0	0	
7 Jun. 1927	0	0	
15 Feb. 1928	102	100	100 confined to tree outside, Nelson
1 Mar. 1928	241	235	76 confined to tree outside, Nelson 159 field, Christchurch

In February 1923, the first shipment of parasitised scales arrived in Nelson. They were taken to Christchurch where nine adults were released (Table 44.1). A few adults were recovered in the following summer but from then until 1928, no parasitoids were observed (Gourlay 1935). However, a newspaper article of 9 August 1927, quoted the curator of the Botanical Gardens, Christchurch, who claimed that the parasitoid had controlled pit scales on the Garden's oaks. The insectary population established from consignment one (Table 44.1) unfortunately died out (DSIR files).

Pit scales with parasitoid-like emergence holes were seen in the insectary in Nelson during November 1925, after the third consignment of *H. dalmanni* was released there (Table 44.1). In December 1925, 260 female *H. dalmanni* were field released in Nelson and in March 1926, emergence holes were observed in some scales. On this evidence, Gourlay (1935) claimed that permanent establishment had occurred. By 1929 the parasitoid was widespread in Nelson (DSIR files). Numerous scales containing pupae of *H. dalmanni* were found in Christchurch in October 1928, on a single tree where only a few females had been released six months beforehand (Table 44.1) (Gourlay 1935).

By 1933, the parasitoid had spread throughout Christchurch and even to Akaroa which was 33 km away, through country with few oak trees (Gourlay 1935). This occurred despite the reputation of *H. dalmanni* as a slow breeder (Anonymous 1936) and weak flyer (Clark 1936) with the inability to disperse between trees about 80 metres apart (DSIR files). However, a rapid spread was also found to occur in Tasmania (Evans 1939) after two

consignments (Table 44.2), and in the Australian Capital Territory from the single importations from New Zealand (Table 44.2) and Tasmania (Evans 1939) in 1937. Such excellent dispersal may be caused by wind-borne adults (DSIR files).

Table 44.2 Distribution of *Habrolepis dalmanni* from Nelson (1929-38) and Christchurch (1936-37). After Gourlay (1935), DSIR files and Wilson (1960).

Year	Number and stage dispatched		Destination
1929	479	adult	Christchurch, North Auckland, Hawke's Bay
	?	pupae	South Canterbury
1930	615	adult	Christchurch, Auckland
	?	pupae	
	(3 consignments)		
1931	10,103	pupae	Christchurch, Dunedin, Auckland, Tasmania (via Canberra)
	50	adult	Christchurch
1932	25,000	pupae	Tasmania (via Canberra) Christchurch, Dunedin, North Canterbury, Taranaki
1933	300	adult	Christchurch
	25,200	pupae	Christchurch, Tasmania
1936	?	pupae	Chile (possibly not sent)
1937	?	pupae	Australian Capital Territory
1938	200	adult	
	?	pupae	South Canterbury

Evaluation

Late in 1933, Gourlay (1935) found relatively high levels of parasitism in a central Christchurch park (27%), the Christchurch Botanic Gardens (38%), in the suburbs (22%) and in Akaroa (53%). In Nelson in February 1934 parasitism was 60%. These figures are much greater than the 'less than 3% average' found in Oregon (Hanson & Miller 1984), 15% in Bulgaria (Tsalev & Vulcheva 1963) or the 29% (summer generation of *H. dalmanni*) and 18% (overwintering generation) recorded in Poland (Podsiadlo 1986).

Both in New Zealand and in Australia *H. dalmanni* provided sufficient control of *Asterodiaspis* spp. to ensure improvement in the health of the oak trees (DSIR files, Miller 1947). In fact, since the 1930s there has apparently been no public concern expressed about scale-infested oak trees in New Zealand. However, unhealthy trees with many unparasitised scales were found in the vicinity of the parasitoid release area in 1988 (Ferguson unpublished) and therefore only partial control has resulted.

Conclusions

Pit scales can still be readily found on Christchurch oaks. In winter 1988, the average density of mature scales on 20 current season's twigs from a single tree was 15 (range 1-68) (Ferguson unpublished), which equates with the figures of Parr (1940). Even at this density, disfigurement of the host is evident. The importation of parasitoids could again be considered although there is no demand for this at present. Hanson & Miller (1984) list promising candidates for biological control.

While it appears that only two pit scale species and one parasitoid are present, a survey of oaks throughout New Zealand should be undertaken to confirm this.

Acknowledgements

I sincerely appreciate the identification of scales by L.M. Emms, MAFQual, Canterbury Agriculture and Science Centre, Lincoln, Canterbury. I also thank K.A.J. Wise, Auckland Institute and Museum, Auckland, for his unpublished opinion of New Zealand *Asterodiaspis* species, and S.R. Pennycook, DSIR, Auckland, for the mycological information.

References

Annecke, D.P.; Mynhardt, M.J. (1970) On some species of *Habrolepis* Foerster and *Adelencyrtus* Ashmead (Hymenoptera: Encyrtidae) in southern Africa and Mauritius. *Entomophaga* 15, 127-148.

Anonymous (1936) Entomological investigations. *Report of the Council for Scientific and Industrial Research 1934-35* 9, 28-34.

Boratynski, K. (1961) A note on the species of *Asterolecanium* Targioni Tozzetti 1869 (Homoptera, Coccoidea, Asterolecaniidae) on oak in Britain. *Proceedings of the Royal Entomological Society of London, series B* 30, 4-14.

Brain, C.K. (1919) The Coccidae of South Africa. Part 4. *Bulletin of entomological research* 10, 95-128.

Brown, L.R.; Eads, C.O. (1965) A technical study of insects affecting the oak tree in Southern California. *Californian Agricultural Experiment Station bulletin* 810, 105 pp.

Clark, A.F. (1936) Biological control of noxious insects and weeds in New Zealand. Part II: Biological control of forest insect pests. *New Zealand journal of science and technology* 18, 585-588.

DSIR, Entomology Division, file BC 1/4.

Edmunds, G.J.; Alstad, D.N. (1978) Coevolution in insect herbivores and conifers. *Science* 199, 941-945.

Evans, J.W. (1939) Oak insects. *Tasmanian journal of agriculture* 10, 199-205.

Gonzales, R.H.; Rojas, P.S. (1967) Estudio analitico del control biologico de plagas agricolas en Chile. *Agricultura tecnica* 26, 133-147.

Gourlay, E.S. (1935) Parasites of the golden oak scale. The establishment in New Zealand of *Habrolepis dalmanni* Westwood. *New Zealand journal of science and technology* 16, 216-235.

Hanson, P.E.; Miller, J.C. (1984) Scale insects on ornamental plants: a biological control perspective. *Journal of arboriculture* 10, 259-264.

Herting, B. (1972) A catalogue of parasites and predators of terrestrial arthropods. Section A, volume 2 : Homoptera. Commonwealth Institute of Biological Control, 210 pp.

Johnson, W.T.; Lyon, H.H. (1976) Insects that feed on trees and shrubs. An illustrated practical guide. Cornell University Press, New York. 464 pp.

Koehler, C.S. (1964) Control of *Asterolecanium* scales and cynipid leaf galls on oak in northern California. *Journal of economic entomology* 57, 579-581.

Miller, D. (1925) Forest and timber insects in New Zealand. *New Zealand Forest Service bulletin* 2, 76 pp.

Miller, L.W. (1947) The biological control of insect pests in Tasmania. *Tasmanian journal of agriculture* 18, 117-119.

Newstead, R. (1903) Monograph of the Coccidae of the British Isles. Vol. 2. Ray Society, London. 270 pp.

Nicholls, H.M. (1933) The oak scales and its parasite. *Tasmanian journal of agriculture* 4, 24-26.

Parr, T. (1940) *Asterolecanium variolosum* Ratzeburg, a gall-forming coccid, and its effect upon the host trees. *School of Forestry, Yale University, bulletin* 46, 49 pp.

Podsiadlo, E. (1975) Life cycle of *Asterodiaspis variolosa* (Ratzeburg, 1870) (Homoptera, Coccoidea, Asterolecaniidae) in Poland. *Annales zoologici* 32, 347-355.

Podsiadlo, E. (1986) Morpho-biological studies on primary parasites (Hymenoptera, Chalcidoidea, Encyrtidae) of scale insects from the genus *Asterodiaspis* Signoret (Homoptera, Coccoidea, Asterolecaniidae) in Poland. *Annales zoologici* 40, 255-296.

Pritchard, A.E.; Beer, R.E. (1950) Biology and control of *Asterolecanium* scales on oaks in California. *Journal of economic entomology* 43, 494-497.

Russell, L.M. (1941) A classification of the scale insect genus *Asterolecanium*. *United States Department of Agriculture miscellaneous publication* 424, 322 pp.

Tillyard, R.J. (1926a) History of the introduction of beneficial insects into New Zealand. *Proceedings of the Pan Pacific Science Congress, Australia, 1923* 1, 383-390.

Tillyard, R.J. (1926b) The insects of Australia and New Zealand. Angus and Robertson Ltd, Australia. 560 pp.

Tsalev, M.; Vulcheva, M. (1963) Data on the bionomics and means of control of the oak scale *Asterodiaspis variolosa* Ratzeburg in Bulgaria. *Rastitelna zashtita* 11, 24-29. (In Bulgarian.)

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Wise, K.A.J. (1977) A synonymic checklist of the hexapoda of the New Zealand sub-region. The smaller orders. *Bulletin of the Auckland Institute and Museum* 11, 176 pp.

Yanin, V.V. (1975). Coccids as pests of park plants. *Zashchita rastenii* 3, 43-45. (In Russian.)

Eriococcus coriaceus Maskell, gum tree scale (Homoptera: Eriococcidae)

C.F. MORALES and J. BAIN

Pest Status

Eriococcus coriaceus, an Australian species, was accidentally introduced into New Zealand probably on small living eucalypt plants or on the bark of hardwood timber imported into South Canterbury for harbour work (Kirk 1908). It was first recorded in New Zealand in 1900 on eucalypts in Timaru and quickly spread through both islands (Clark 1936). It has been reported from many *Eucalyptus* species, notably, *E. globulus* Labillardière but also *E. viminalis* Labillardière, *E. macarthuri* Deane & Maiden, *E. gunnii* Hooker, *E. obliqua* L'Héritier de Brutelle, *E. regnans* von Müller and a few others including ornamentals such as *E. cinerea* F. Muell. ex Benth. (Clark 1936, Zondag 1977). Miller (1944) also records it from apricot and *Salix* sp.

In large numbers this scale can cause debility or death of susceptible varieties of *Eucalyptus*. The growth of sooty mould promoted by the scale's feeding activity inhibits photosynthesis, and die-back of terminal twigs and epicormic shoots of *E. globulus* is also thought to be caused by the gum tree scale (Kirk 1908).

Each adult female produces several hundred eggs which hatch into crawlers that settle on the leaf midribs, twigs and the bark of young trees where they stay for the rest of their life. There are two to three generations a year in New Zealand (Miller & Clark 1935).

Background

Very shortly after its establishment *Eriococcus coriaceus* was recognized as a very significant pest of eucalypts, particularly *Eucalyptus globulus*, and the planting of this species virtually ceased (Kirk 1908). Kirk (1908) contacted W.W. Froggatt in New South Wales and asked him to send shipments of 'those ladybirds that were known to prey on the scale'. At the same time Kirk arranged for consignments of *Rhyzobius ventralis* (Erichson), *Cryptolaemus montrouzieri* Mulsant and *Orcus chalybeus* (Boisduval) to be sent from Auckland to South Canterbury where the problem with *E. coriaceus* was most severe. These three species of coccinellids were already present in the country, having been introduced to control various species of scale insects (Dumbleton 1936).

Froggatt (1900) gave an account of the parasitoids and predators of *E. coriaceus* in Australia. Amongst others he specifically mentioned *Rhyzobius ventralis* and *Cryptolaemus montrouzieri*. A.L. Tonnoir of the Bureau of Entomology, Canberra, investigated the position of *Eriococcus* spp. in Australia and it was as a result of this that several species of predators were introduced into New Zealand.

R. ventralis has a relatively limited host range (Richards 1981), and it is generally regarded as being best adapted to feeding on Eriococcidae, consuming all stages of its major prey, *E. coriaceus*, with great voracity (Richards 1981, Zondag 1977). Minor hosts are listed by Richards (1981). Although it has been recorded feeding on *Icerya purchasi* Maskell, it has not been found feeding on this scale on citrus (Pope 1981, Richards 1981). Koebele (1890), during his first expedition to Australia to collect natural enemies of the cottony cushion scale, noted that *R. ventralis* was 'only occasionally found with *Icerya*, yet very abundant on various eucalypt scales, especially on *Eriococcus eucalypti*'.

Both adults and larvae feed on *E. coriaceus* (Richards 1981), but the brownish black larvae do most of the feeding (Bartlett 1978). In New Zealand *R. ventralis* has at least two generations per year (Clark 1938). In Sydney it is usually univoltine but this may increase if there is plenty of food and the temperature and photoperiod are suitable (Richards 1981).

The fecundity of each female is not known, but it is assumed to be adequate to keep pace with its prey (Kirk 1908, Richards 1981). The adult lifespan is not known, but Richards (1981) stated that it must be relatively long. This conclusion is based on her laboratory rearings, plus reports by Koebele (1890, 1893) and Froggatt (1902) of large groups of *R. ventralis* adults hiding under *Eucalyptus* spp. bark, and the ability of the adults to undergo a reproductive diapause for considerable periods in the absence of food. There have been no records of predation or parasitism on *R. ventralis* and competition with other predators has not been reported in New Zealand.

R. ventralis, *Orcus chalybeus* and *Cryptolaemus montrouzieri* were already established in New Zealand prior to *E. coriaceus* being recognised as a problem here. *O. chalybeus* was introduced in 1899 to control black scale, *Saissetia oleae* (Olivier) and *C. montrouzieri* in 1897 against mealybugs (Dumbleton 1936). It would seem that the main *Rhyzobius* species that was introduced against black scale was in fact *R. forestieri* (Mulsant) although it was referred to as *R. ventralis*. We are of the opinion that there must have been more than one shipment about 1899 or that the shipment must have contained both species, viz. *R. forestieri* and *R. ventralis*.

Importations, Releases and Recoveries

Rhyzobius ventralis (Erichson) (Coleoptera: Coccinellidae)

In 1905 Kirk introduced *R. ventralis* from Australia. Successive consignments were received and widely distributed in infected plantations (Kirk 1908). It soon became established and spread readily where there were *E. coriaceus* populations. This spread was materially assisted by artificial distribution of insects from 'breeding stations' in South Canterbury (Kirk 1908). *E. coriaceus* first reached the North Island in 1921 (Clark 1936) and in that same year large quantities of *R. ventralis* were shipped from the South Island to the North Island resulting in its rapid establishment there. Its present distribution is in the Auckland area, Hawke's Bay, Bay of Plenty, Taranaki, Wairarapa, Wellington, Marlborough, Nelson and Canterbury (Pope 1981, DSIR files, P. Lovis pers. comm., R. Emberson pers. comm.).

Orcus chalybeus (Boisduval) (Coleoptera: Coccinellidae)

In 1905 Kirk imported *O. chalybeus* from Australia and they were released near Timaru, South Canterbury. Apparently the species did establish there but was never recovered in great numbers (Kirk 1908).

Pseudoleucopsis benefica Malloch (Diptera: Chamaemyiidae)

In 1932 a small consignment of this species was received from Australia and released at Palmerston North (Clark 1936, Miller & Clark 1935). Poor emergences from the imported material resulted in only 11 adults being released and the species did not establish (DSIR files).

Stathmopoda melanochra Meyrick (Lepidoptera: Stathmopodidae)

In 1932 and 1933 more than 100 adult *S. melanochra*, imported from Australia in two shipments, were released in Nelson (DSIR files, Miller & Clark 1935). Six adults were liberated in the 1932 season and 91 in the 1933 season (Miller & Clark 1935). It has become established in Nelson and Christchurch (J. Dugdale pers. comm., Forest Research Institute (FRI) files), Hawke's Bay (P. Watts pers. comm.) and Manawatu (FRI files).

Catoblemma mesotaenia Turner (Lepidoptera: Noctuidae) and *Creobota coccophthora* Turner (Lepidoptera: Pyralidae)

An attempt was made to introduce both these Lepidoptera in 1932 but they did not survive transportation from Australia (Miller & Clark 1935).

Evaluation

The efficient and rapid control of gum tree scale by *R. ventralis* is considered to be one of the great successes in the use of biological control agents against insect pests in New Zealand. As a result of predation by *R. ventralis*, *E. coriaceus* is now not a major pest in New Zealand (Zondag 1977). Richards (1981) considered that *R. ventralis* was successful because of its specificity in food preferences, voracity, lack of competition by other natural enemies, and the ability to produce as many or more generations than its prey. The subsequent cultivation of less susceptible varieties of *Eucalyptus* spp. has also reduced the pest status of gum tree scale (Scott 1984). Small outbreaks of the scale have occurred as it has moved to new areas. As the predators have poor powers of dispersal, artificial re-distribution of the ladybird has been required, but has successfully controlled new infestations (Bartlett 1978, Clark 1936).

S. melanochra is never abundant enough to exert any marked effect on *E. coriaceus* populations, and *C. montrouzieri* and *O. chalybeus* are usually only found in the northern, warmer parts of the country and have very little effect on *E. coriaceus*.

Conclusions

E. coriaceus is now a minor pest of *Eucalyptus* spp. and does not warrant further biological control attempts.

Literature Cited

Bartlett, B.R. (1978) Coccidae. Pp. 57-131 in Clausen, C.P. (ed.) Introduced parasites and predators of arthropod pests and weeds: a world review. *United States Department of Agriculture, Agricultural Research Service, Agriculture Handbook* 480.

Clark, A.F. (1936) Biological control of forest insect pests. *New Zealand journal of science and technology* 18, 585-588.

Clark, A.F. (1938) A survey of the insect pests of eucalypts in New Zealand. *New Zealand journal of science and technology* 19, 750-751.

DSIR, Entomology Division, file BC 1/4.

Dumbleton, L.J. (1936) The biological control of fruit pests in New Zealand. *New Zealand journal of science and technology* 18, 588-592.

Forest Research Institute, file E86.

Froggatt, W.W. (1900) Notes on Australian Coccidae (scale insects). *New South Wales agricultural gazette* 11, 99-107.

Froggatt, W.W. (1902) Australian ladybirds. *Agriculture gazette of New South Wales* 23, 895-911.

Kirk, T.W. (1908) Gum tree blight and the natural enemy. Report of the Department of Agriculture, New Zealand. 117-122.

Koebele, A. (1890) Report of the fluted scale of the orange and its natural enemies in Australia. *Bulletin of the Bureau of the Entomology Department of the United States Department of Agriculture* 21, 9-32.

Koebele, A. (1893) Studies of parasitic and predaceous insects in New Zealand, Australia and adjacent islands. *United States Department of Agriculture report* 51, 39 pp.

Miller, D. (1944) Garden pests in New Zealand and how to control them. Whitcombe & Tombs, Wellington, 2nd ed. (revised and enlarged). 149 pp.

Miller, D.; Clark, A.F. (1935) Control of forest insects. Distribution of parasites in New Zealand. *New Zealand journal of science and technology* 16, 301-307.

Pope, R.D. (1981) '*Rhyzobius ventralis*' (Coleoptera: Coccinellidae), its constituent species, and their taxonomy and historical roles in biological control. *Bulletin of entomological research* 71, 19-31.

Richards, A.M. (1981) *Rhyzobius ventralis* (Erichson) and *R. forestieri* (Mulsant) (Coleoptera: Coccinellidae), their biology and value for scale insect control. *Bulletin of entomological research* 71, 33-46.

Scott, R.R. (1984) New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Zondag, R. *1977 Eriococcus coriaceus* Maskell (Hemiptera: Coccoidea: Eriococcidae) gum-tree scale. *Forest and timber insects in New Zealand* 22. New Zealand Forest Service, Wellington. 4pp.

Gonipterus scutellatus Gyllenhal, gum tree weevil (Coleoptera: Curculionidae)

M.J. NUTTALL

Pest Status

The gum tree weevil *Gonipterus scutellatus*, native to Australia, was first recorded in New Zealand in 1890 (Thomson 1922). It occurs throughout the country feeding both as both larva and adult on the leaves and young shoots of various *Eucalyptus* species. Adults scallop leaf edges and eat the soft bark of shoots, but most damage is caused by the larvae which destroy the whole surface of the leaf apart from the hard fibres. Repeated defoliation can result in stunted tree growth. The most favoured hosts are *E. globulus* Labillardière and *E. viminalis* Labillardière while narrow leaved species such as *E. linearis* Dehnhardt and *E. pulchella* Desfontaines are rarely attacked (Clark 1931, Bain 1977). Adults overwinter under the loose bark of eucalypts, especially *E. globulus*, and in spring move to young foliage where eggs are laid in small black cases about 3 mm long stuck to the leaves. Each case contains between seven and 16 eggs. The emerging larvae eat their way through the leaf on which the case was fixed and start browsing the underside. The larval period usually lasts four to five weeks and the larvae then fall to the ground and pupate in the soil. Adults emerge in December and January, and the cycle is repeated to produce a second generation of adults in March-April which hibernate for the winter. In cooler districts there is only one generation a year with the adults which emerge December-January feeding and then hibernating without laying eggs (Bain 1977).

Although damage by the gum tree weevil is now considerably overshadowed by that caused by another introduced beetle *Paropsis charybdis* Stål (Chrysomelidae), the weevil is still regarded as an important defoliator of certain eucalypts (Bain 1977).

Background

By the mid 1920s the gum tree weevil had become a major pest of eucalypts in New Zealand. It was also of similar concern in South Africa and an entomologist from there, F.C. Tooke, was sent to Australia to obtain parasitoids. Amongst those discovered was an undescribed mymarid which parasitised the eggs of the weevil (Miller 1927). This mymarid, *Anaphoidea nitens* Girault 1928, was later placed in the genus *Patasson* and most recently *Anaphes*.

Also found was a tachinid parasitoid of gum tree weevil larvae (Tooke 1955), later described by Malloch as *Froggattimyia lasiophthalma* (DSIR files).

Importations, Releases and Recoveries

Mymarid

As well as sending shipments of gum tree weevil egg cases parasitised by the mymarid to South Africa Tooke also sent a consignment in October 1927 to D. Miller then Government Entomologist attached to the New Zealand Department of Agriculture. The 190 mymarids which emerged in October and November 1927 were used to infest weevil eggs in an insectary and from these, four to six weeks later, many adults emerged. Most were liberated while the remainder were used to parasitise eggs in the insectary. Liberations were made in the North Island at Henderson (Auckland); Mangaiti (Bay of Plenty); Orini (Waikato); 'Waitapu'

(believed to be Waiotapu); Waipukurau (Hawke's Bay); Bulls, Marton, Palmerston North and Wellington; and in the South Island at Blenheim, Motueka, and Darfield (Mid Canterbury) (Miller 1928, DSIR files).

In the following season, 1928-29, collections of weevil egg cases from Wellington and Darfield failed to produce any mymarids, and none emerged from parasitised egg cases held in the insectary (DSIR files). It was therefore decided to reintroduce the parasitoid and in the 1929-30 season three consignments of parasitised egg cases were obtained from the Australian Bureau of Entomology by D. Miller, then Director of Research of the newly formed Forest Biological Research Station, Department of Scientific and Industrial Research, working in association with the Cawthron Institute, Nelson. Three generations were reared in the insectary. Liberations of 486 adults were made locally around Nelson, and parasitised egg cases were sent to the other South Island localities of Takaka (Nelson), Ashburton and Darfield. In January 1930 progeny of the original 1927-28 introduction were recorded at Auckland and Cambridge proving that the insect was established in these localities at least, and that natural spread had occurred. Work of rearing further supplies of parasitoids was therefore discontinued and the parasitised material of the fourth insectary generation of the 1929-30 season was distributed to Waipukurau (Clark 1931, DSIR Annual Report 1931, DSIR files).

Attempts to recover the mymarid from around Nelson were unsuccessful and in the 1930-31 season a small number of weevil egg capsules was obtained from Auckland. The adults which emerged were used for insectary oviposition. Parasitised egg capsules were distributed in the Taranaki, Hawke's Bay and Auckland Provinces whilst adults were liberated in the Nelson district (Clark 1931). It is possible that further liberations were made in the South Island in the 1931-32 season but this is unclear from the records. In the 1935-36 season mymarids, that presumably had emerged from weevil egg cases sent for check on parasitoid establishment, were released in at Hanmer Springs (Mid Canterbury) and Nelson (DSIR files).

In 1936 Clark reported that the mymarid was well established in all the important districts of the North Island. In the South Island many introductions had been made and the parasitoid was well established in at least the Nelson Province and possibly in the more southern areas (Clark 1936). The difficulty of establishing it in the south was thought to be related to the single generation life cycle of the host in cooler districts.

Since the early 1930s no further releases of the mymarid have been necessary. It is known to occur throughout New Zealand.

Other parasitoids

Eighteen specimens of a chalcid emerged following the emergence of most of the mymarids from the initial consignment of weevil egg cases in 1927. It was not known if this chalcid was a primary parasitoid or a hyperparasitoid, and none were released (Miller 1927). One of the three consignments of egg cases imported in the 1929-30 season was believed to be parasitised by chalcids only (Clark 1931) but there is no record of any emerging. The name and status of this chalcid are not stated.

In 1934 an enquiry was made by Clark to the Division of Economic Entomology about the possibility of obtaining the larval (tachinid) parasitoid of the gum tree weevil. *Gonipterus* larvae (presumably parasitised) sent from Australia were reported as arriving in good order December 1934 (DSIR files). Later Clark (1938) stated that 'The possibility of securing a tachinid larval parasitoid has already been investigated and the indications are promising'. There is no record of what if anything emerged from the 1934 importation of larvae, whether any further importations were attempted, or whether any tachinids were ever liberated. The Nelson research station closed in 1938 and Clark left (de Gryse 1955).

Evaluation

Before the introduction of the mymarid the only enemies of the gum tree weevil in New Zealand were the pentatomids *Cermatulus nasalis* (Westwood) (Clark 1931), and *Oechalia schellembergii* (Guérin-Méneville). These general predators had little effect on gum tree weevil numbers. However so rapid was the impact of the specialised egg parasitoid that after only two years following its initial release there was a noticeable absence of weevils in Auckland and a marked improvement in the condition of the trees there (Clark 1931). The same author stated five years later that the 'numerical strength of the weevil' was diminishing rapidly wherever the mymarid was established (Clark 1936). The rate of parasitism was high. In Auckland 70-80% of weevil eggs were found to be parasitised in capsules collected at random (Clark 1938). A general low incidence of gum tree weevil attack has continued to the present day.

Conclusions

The establishment of the mymarid is an excellent example of successful biological control. It rapidly reduced host numbers and then maintained them at a low level. There is no reason to believe that the situation will alter in the future.

Literature Cited

Bain, J. (1977) *Gonipterus scutellatus* Gyllenhal (Coleoptera : Curculionidae) gum-tree weevil. *Forest and timber insects in New Zealand* 8, New Zealand Forest Service, Wellington. 4 pp.

Clark, A.F. (1931) The parasitoid control of *Gonipterus scutellatus* Gyll. *New Zealand journal of science and technology* 13, 22-28.

Clark, A.F. (1936) Biological control of forest insect pests. Pp. 585-588 in Miller, D.; Clark, A.F.; Dumbleton, L.J., Biological control of noxious insects and weeds in New Zealand. *New Zealand journal of science and technology* 18, 579-593.

Clark, A.F. (1938) A survey of the insect pests of eucalypts in New Zealand. *New Zealand journal of science and technology* 19, 750-761.

DSIR, Annual Report (1931).

DSIR, Entomology Division, file BC 1/4.

de Gryse, J.J. (1955) Forest pathology in New Zealand. Bulletin 1. New Zealand Forest Service, Wellington, 62 pp.

Miller, D. (1927) The gum-tree weevil and its parasites. Preliminary control work in New Zealand. *New Zealand journal of agriculture* 35, 283-289.

Miller, D. (1928) Establishment of beneficial insects in New Zealand. Summary of recent work under Agriculture Department. *New Zealand journal of agriculture* 37, 193-195.

Thomson, G.M. (1922) The naturalisation of animals and plants in New Zealand. Cambridge University Press, London, 607 pp.

Tooke, F.G.C. (1955) The eucalyptus snout beetle *Gonipterus scutellatus* Gyll. A study of its ecology and control by biological means. *Entomology Memoirs, South Africa* 3, 282 pp.

Hylastes ater (Paykull), black pine bark beetle and *Hylurgus ligniperda* (Fabricius), golden haired bark beetle (Coleoptera: Scolytidae)

W. FAULDS

Pest Status

The black pine bark beetle *Hylastes ater* (Paykull), was accidentally introduced into New Zealand from Europe where it is widely distributed. In New Zealand it was first found in Foxton, in the Manawatu in large numbers in 1929 (Clark 1932) but was probably present well before this and is now distributed throughout the country (Milligan 1978). *Hylastes ater* is also an accidentally introduced species in Australia (Milligan 1978).

Hylurgus ligniperda (F.) is widely distributed in Europe, the Mediterranean area and Atlantic islands and is established as an introduced species in Japan, parts of South Africa and South America, Sri Lanka and southern Australia. It was first discovered in New Zealand in 1974 near Whitford south of Auckland (Bain 1977) and is now found throughout the North Island and in Nelson, Marlborough, Canterbury as far south as South Canterbury and in parts of north Westland (Forest Research Institute (FRI) files).

Adults and larvae of both *H. ater* and *H. ligniperda* generally feed in the inner bark of recently felled logs and stumps. The preferred attack site on a log is that part of the log in contact with the ground, and in stumps brood galleries are mostly made in the roots (Bain 1977, Milligan 1978).

From the economic viewpoint the most important problem with *H. ater* is that infested export logs must either be refused for export or fumigated immediately before shipping, while green sawn timber may have to be fumigated, or kiln sterilised if adults which have been attracted to the freshly sawn wood are present on its surface (Milligan 1978). Eventually *H. ligniperda* will probably cause the same problem (Bain 1977). It has been estimated that in the Bay of Plenty alone *H. ater* can cause annual expenditure of up to NZ$250,000 on fumigation (Zondag 1979). *Hylastes ater* adults are also reported to attack and kill newly planted stock and sometimes natural regeneration (Zondag 1965). However, Forest Research Institute trials strongly suggest that significant losses associated with wounds made by the beetles occur only when the host tissues are so weakened by poor growing conditions that they are unable to produce a normal flow of resin in response to wounding. *Hylastes ater* adults may feed on seedlings of *Pinus* (pine), *Picea* (spruce), *Abies* (fir), *Larix* (larch) and *Pseudotsuga menziesii* (Douglas fir) but broods are usually reared in pine (Milligan 1978). *Hylurgus ligniperda* is apparently restricted to pine (Bain 1977).

Background

After a thorough investigation Miller & Clark (1935) reported no evidence of parasites or predators attacking any stage of *Hylastes ater* in New Zealand. They also suggested it was unlikely that parasites or predators of native bark beetles would effect any control. With the prospect that *H. ater* would become a serious pest when the future large scale utilisation of introduced conifers commenced, it was thought that no other method or practice to combat this insect would be as successful as biological control.

Importations, Releases and Recoveries

The first introduction of a control agent was made in 1933 when three *Rhizophagus* species from Europe, *R. bipustulatus* (F.) *R. dispar* (Paykull) and *R. ferrugineus* (Paykull) were released in several areas (Miller & Clark 1935). No further biological control efforts were made until 1972 when the Forest Research Institute contracted the Commonwealth Institute of Biological Control to look into the possibility of obtaining parasitoids and predators. In 1975 two pteromalid parasitoids, *Rhopalicus tutela* (Walker) and *Dinotiscus eupterus* (Walker) were received. Rearing *D. eupterus* failed. Although *R. tutela* was successfully reared and released, it was considered that the chances of it exercising a marked control of *H. ater* were small (FRI files). It was thought that a predatory beetle would be more effective than the parasitoids and in 1976 the CIBC forwarded adults and larvae of the clerid *Thanasimus formicarius* (L).

Rhizophagus species (Coleoptera: Rhizophagidae)

In 1933 at the request of the New Zealand State Forest Service for suitable parasitoids for *H. ater*, W.R. Thompson, of the Farnham House Laboratory (now CIBC), forwarded 3,711 specimens of three *Rhizophagus* species known to be predaceous on the larvae and pupae. Little information was available at that time concerning parasitoids and predators of *H. ater* in Europe and *Rhizophagus* spp. were chosen because it was considered they would be the most suitable for transportation. These predators were transported as adults in cool storage. Mortality was quite high. Rearing was not attempted except to show that the fertility of the females had not been impaired by cool storage, and the majority of live adults were released directly into the main centres of *H. ater* infestation (Table 47.1). More predators were received at a later date (Cawthron Institute 1936) but there is no record of how many or if any releases were made. Field investigations, between October and December 1935, found no definite evidence of establishment of these insects (Cawthron Institute files) and none has subsequently been found in New Zealand.

Table 47.1 Releases of *Rhizophagus* species 1933

Locality	*Rhizophagus dispar*	*Rhizophagus bipustulatus*	*Rhizophagus ferrugineus*
Hanmer Springs	200		
Braeburn		75	
Moutere Hills			30
Foxton	200		50
Rotorua		75	
Wairakei		160	
Taupo		75	
Total	400	385	80

Rhopalicus tutela (Walker) and *Dinotiscus eupterus* (Walker) (Hymenoptera: Pteromalidae)

Between July and September 1975 seven consignments of these bark beetle larval parasitoids were received from the CIBC substation in Austria. Altogether 1653 live adults were received and the majority of these were female *R. tutela*. In September 1976 a further 230 live parasitoids arrived in three consignments which also included *Thanasimus formicarius* adults and larvae.

From December 1975 to April 1977 8996 reared *R. tutela* adults were released into five forests (Table 47.2). Bark beetle infested logs have been collected for laboratory rearing of

Table 47.2 Releases of *Rhopalicus tutela*

Forest	*Rhopalicus tutela*	Number of release sites
Kaingaroa	2948	
Woodhill	4625	3
Waiuku	489	2
Whakarewarewa	449	2
New Zealand Forest Products. Tokoroa	485	1
Total	8996	15

T. formicarius from both Kaingaroa and Woodhill forests from 1976 to 1985 but no *R. tutela* have emerged from these logs.

Thanasimus formicarius (L). (Coleoptera: Cleridae)

In September 1976 three consignments, totalling 214 adults and 165 larvae, of *T. formicarius* were sent to the Forest Research Institute from the CIBC substation in Austria. The adult of this beetle preys on bark beetle adults and the larva on bark beetle larvae. It was successfully reared, initially in quarantine rooms and later in insectaries. From mid April 1977 to the end of April 1987 a total of 12,385 reared adults (Table 47.3) was released into 17 forests: Woodhill, Waiuku, Kawhia, Rotoehu, Tarawera, Matahina, Whakarewarewa, Kaingaroa, New Zealand Forest Products Tokoroa, Tauhara, Patanamu, Pouakani, Karioi, Waiterere and Gwavas forests in the North Island and Rabbit Island and Golden Downs in the South Island. In some of these forests several releases were made at different sites but always onto logs with bark beetle infestations. Most were mated prior to release.

On 29 February 1984 three larvae were found under the bark uppermost from the ground of a bark beetle infested pine log in Whakarewarewa Forest. Ten male and 10 female adults had been released in the same stand in December 1979. Other releases made before 1984 in Whakarewarewa Forest were in 1978 and in March and April 1982 (FRI files) into areas well away from this stand.

Table 47.3 Annual releases of *Thanasimus formicarius*

Year	*Thanasimus formicarius*
1977	176
1978	616
1979	1925
1980	1087
1981	361
1982	1020
1983	1084
1984	2907
1985	2173
1986	636
1987	400
Total	12385

Evaluation

It seems that the *Rhizophagus* species were selected for biocontrol of *H. ater* mainly because of their suitability to be transported (Miller & Clark 1935). However, due to the lack of information at that time about predators and parasitoids of *H. ater* it is unlikely that this was the correct choice.

Rhopalicus tutela cannot burrow into soil and is reported (FRI files) as being more suited to parasitise bark beetle larvae under the bark of standing trees or in logs not in contact with the ground. Forest operations in New Zealand now produce much less waste than in previous times, and the bulk of material left for bark beetles to breed in is the roots of stumps or other buried material, i.e. totally unsuitable for *Rhopalicus*. There is no evidence that this parasitoid is established but if it is, it will have no major influence on bark beetle populations.

Thanasimus formicarius has been recovered only from Whakarewarewa Forest but is probably established in other localities. In Europe this beetle is generally found with bark beetle infestations of standing trees or exposed logs, and although the larvae are mobile under the bark and could reach some parts of logs and stumps below ground (FRI 1978), many *H. ater* larvae would still be inaccessible.

Both *Thanasimus formicarius* and the pteromalids sent to New Zealand were reared from logs from which *H. ater* constituted less than 1.7% of emerging bark beetles compared with over 90% for *Hylurgops palliatus* (Gyllenhal) (Scheibelreiter 1976). Most of the emerging parasitoids and predators were probably reared from bark beetles other than *Hylastes ater* and most likely from *Hylurgops palliatus*. This was considered by Scheibelreiter when parasitoids and predators were selected, but it was thought that because many species had a wide host range those sent should be able to attack *Hylastes ater*. Unfortunately *H. ater* differs remarkably from *Hylurgops palliatus* in its habitat (Munro 1916). The former breeds in roots and the latter in stems and crowns. It seems therefore that *T. formicarius* will be unable to control *H. ater* in the larval stage. Control, if any, could only come from the adults which catch and eat bark beetle adults as they alight on logs. The accidental introduction of *Hylurgus ligniperda* into New Zealand (Bain 1977) might facilitate the establishment of *T. formicarius*, as this bark beetle often breeds under the bark of the exposed part of logs.

Justification for the biological control of *Hylastes ater* originally arose from concern about its effect on re-establishment of pine in cut over areas (Clark 1932), but this seems no longer valid in the light of more recent information (Milligan 1978). From the quarantine aspect, because a solitary insect is enough to warrant fumigation of export logs and timber, no biological control programme could hope to lower *H. ater* and *Hylurgus ligniperda* numbers to a level where fumigation would be greatly reduced. Recent changes in forest hygiene practices have probably been far more effective in reducing numbers than any biological agent.

Conclusions

Only *T. formicarius* has definitely become established. However, as most *Hylastes ater* and *Hylurgus ligniperda* broods are reared too far below the ground to be accessible to *T. formicarius* it seems unlikely that this predator will significantly reduce bark beetle populations.

Because it appears very doubtful that *Hylastes ater* is responsible for seedling mortality, and also because *H. ater* and *Hylurgus ligniperda* populations are unlikely to be controlled biologically to a level where fumigation costs of export material will be reduced, no future attempts to introduce biocontrol agents for these bark beetles should be made. If any future attempt is made the insects selected should be those which are found normally associated with bark beetles in buried logs and roots, and not those which are restricted to bark beetles in exposed logs and standing trees.

Literature Cited

Bain, J. (1977) *Hylurgus ligniperda* (Fabricius) (Coleoptera: Scolytidae). *Forest and timber insects in New Zealand* 18. New Zealand Forest Service, Wellington. 6 pp.

Cawthron Institute, file BC 1/4.

Cawthron Institute (1936) Annual report, pp. 12.

Clark, A.F. (1932) The pine-bark beetle, *Hylastes ater*, in New Zealand. *New Zealand journal of science and technology* 14, 1-20.

Forest Research Institute, file E86.

Forest Research Institute (1978) Annual report, pp. 40-41.

Miller, D.; Clark, A.F. (1935) Control of forest insect pests. Distribution of parasites in New Zealand. *New Zealand journal of science and technology* 16, 301-7.

Milligan, R.H. (1978) *Hylastes ater* (Paykull) (Coleoptera: Scolytidae) black pine bark beetle. Forest and timber insects in New Zealand, 29. New Zealand Forest Service, Wellington. 8 pp.

Munro, J.W. (1916) The genus *Hylastes*, Er., and its importance in forestry: a study of scolytid structure and biology. *Proceedings of the Royal Physical Society of Edinburgh* 20, 1915-1923, 123-158.

Scheibelreiter, G.K. (1976) Investigations on the possibilities of biological control measures against *Hylastes ater* and *Criocephalus ferus* Muls. in New Zealand (Work in Europe 1973-1976). Commonwealth Institute of Biological Control, Project for New Zealand final report & progress report no. 4. 16 pp.

Zondag, R. (1965) Insect pests of forest nurseries and young plantations in New Zealand. *Proceedings of the 12th International Congress of Entomology*, London, 674-675.

Zondag, R. (1979) Breeding of the clerid *Thanasimus formicarius* for the control of the bark beetles *Hylastes ater* and *Hylurgus ligniperda* in New Zealand. *New Zealand journal of forestry science* 9, 125-32.

Megastigmus spermotrophus Wachtl, Douglas fir seed chalcid (Hymenoptera: Torymidae)

M.J. NUTTALL

Pest Status

The Douglas fir seed chalcid *Megastigmus spermotrophus* Wachtl, native to western North America (MacDougall 1906), became established in New Zealand in the 1920s (Valentine 1970) and occurs throughout the country. It was introduced in the seed of its only host, Douglas fir (*Pseudotsuga menziesii*) (Bain 1977).

The adults fly in springtime and females lay eggs into the seeds contained in young cones, normally one egg per seed. If more than one egg is laid in a seed only one larva will survive. The larva is fully grown in six to seven weeks and the whole contents of the seed is destroyed. There is a resting stage which normally lasts until the following spring when pupation occurs. The resulting adult cuts a circular exit hole through the seed coat and emerges. Most adults appear after one year but some can emerge two and even three years after oviposition (Hussey 1955, 1961, Bain 1977).

Generally the effect of this insect on Douglas fir seed production is not great but locally in certain years the losses can exceed 20%. Losses are worst in poor seed years as then the percentage of seed attacked is greatest. A considerable amount of effort can be wasted collecting non-viable seed (Bain 1977).

Background

In 1951 two pteromalids, *Mesopolobus spermotrophus* Hussey (= *Amblymerus ?apicalis* Thomson) and *Agnomus strobilorum* (Thomson), were recorded in Scotland as ectoparasitoids of larvae of *Megastigmus spermotrophus* (Hussey 1952). Since *Mesopolobus spermotrophus* will not seek out its host once the cones or seed have been shed from the tree (Hussey 1955), it was considered that breeding of the parasitoid in the laboratory would not be successful. In experiments at the Forest Research Institute (FRI) *Mesopolobus spermotrophus* showed no interest in extracted seed (FRI files), and so only direct field releases were practicable.

Importations, Releases and Recoveries

In 1954 in response to a request by the Forest Research Institute to N.W. Hussey, University of Edinburgh, cones were collected from three areas of Scotland where the parasitoids were present. Some 1.8 kg of seed was extracted and sent by air to Rotorua in January 1955. Before dispatch sample dissection of seeds showed approximately 70% of good seed to be infested with *Megastigmus spermotrophus* and of this 48% were parasitised. A further consignment of about 230 g of seed from cones collected in 1955 was sent in January 1956.

Mesopolobus spermotrophus can only parasitise *Megastigmus spermotrophus* larvae when Douglas fir cone scales open just before seed fall (Hussey 1961). Therefore rearing had to be timed to produce emerging adults in late summer. The seed which arrived in January 1955 was divided into 40 lots, and in an attempt to break the diapause or resting stage of the fully grown larvae most of these lots were subjected to various times in cool storage

before being incubated (22-24°C). Others were incubated without previous cool treatment. Humidity was also varied between some lots. A total of 1,211 males and 651 females emerged, and in February and March 1955 liberations were made amongst cone bearing Douglas fir trees in the North Island forests of Kaingaroa (751 males : 378 females) and Whakarewarewa (209 males : 132 females), and the South Island forest of Hanmer (251 males : 141 females) (FRI 1955). The best emergence was from seed lots that had been subjected to incubation only. Seven females and 180 male *Agnomus strobilorum* were also reared but none were released. The seed lots were returned to the cool store, and at the beginning of 1956 were reincubated. It is uncertain what emergence then occurrred. Some references (FRI 1956, Rawlings 1959) say 'large numbers' of *Mesopolobus spermotrophus* emerged and were liberated, but neither FRI (1958) which summarises releases in previous years, nor FRI files, mention any emergence or liberation in 1956. Whatever did emerge would have been released in Kaingaroa and Whakarewarewa forests.

The seed sent from Scotland in January 1956 was placed in cool storage for the remainder of the year and then incubated. A 'very small number of males' emerged together with an unrecorded number of females, and in February and March 1957 releases were made in Hanmer and another South Island forest, Dusky (FRI 1957). The numbers were not recorded, but it is believed that there were approximately 150 individuals liberated in the former and 100 in the latter (FRI files).

In 1963 and 1964 cones were collected from the forests in which *Mesopolobus spermotrophus* had been released. *Megastigmus spermotrophus* infested seed was present in all collections, but no *Mesopolobus spermotrophus* emerged (FRI files). No special check of Douglas fir seed has been made since that time, and there is no record of the parasitoid emerging from general seed collections made by the New Zealand Forest Service.

Evaluation

Douglas fir cone production varies from year to year. As 1955 was a good seed year it was thought that the parasitoid had a good chance of establishment in at least two of the three forests in which it had been released. However, 1956 was extremely poor for seed production (Rawlings 1959), and any progeny from the first releases would have had difficulty in finding hosts. There would similarly be little chance for any adults which may have been released that year. In 1957 only two forests were at all suitable for liberation. At Hanmer there were a few small areas which had moderate to good seed crops, while at Dusky only trees on compartment margins were heavy cone bearers (FRI files). Although at Dusky *Mesopolobus spermotrophus* were released on such a marginal tree almost all flew rapidly into the interior of the compartment. This preference for a situation in which there had been little seed production would have counted against establishment.

It is also possible that climatic variations at the time of release may have meant that cones were not sufficiently open for *Mesopolobus spermotrophus* to reach infested seed, or conversely seed fall might have been slightly earlier than usual.

Conclusions

Mesopolobus spermotrophus has not been recovered since its release over 30 years ago. If this work is ever to be repeated greater attention will have to be paid to the behaviour of the parasitoid. The main difficulties with the introduction of parasitoids of *Megastigmus spermotrophus* is the restricted time in which infested seed can be reached, and the great variability from year to year of seed production by the tree.

Literature Cited

Bain, J. (1977) *Megastigmus spermotrophus* Wachtl (Hymenoptera: Chalcidoidea: Torymidae). *Forest and timber insects in New Zealand* 14. New Zealand Forest Service, Wellington. 4 pp.

Forest Research Institute, file E86.

Forest Research Institute (1955) Annual report, pp. 15, 55.

Forest Research Institute (1956) Annual report, pp. 20, 60.

Forest Research Institute (1957) Annual report, pp. 17, 52-53.

Forest Research Institute (1958) Annual report, pp. 22, 73.

Hussey, N.W. (1952) A new record of *Megastigmus* (Hymenoptera Chalcididae) in Scotland with a note on the first recorded parasites of *Megastigmus spermotrophus* Wachtl. *Scottish forestry* 6, 53-55.

Hussey, N.W. (1955) The life-histories of *Megastigmus spermotrophus* Wachtl (Hymenoptera: Chalcidoidea) and its principal parasite, with descriptions of the developmental stages. *Transactions of the Royal Society London* 106, 133-151.

Hussey, N.W. (1961) *Megastigmus* flies attacking conifer seed. Forestry Commisssion Leaflet No 8. H.M. Stationery Office, London. 10 pp.

MacDougall, R.S. (1906) *Megastigmus spermotrophus* Wachtl, as an enemy of Douglas Fir (*Pseudotsuga Douglasii*). *Transactions of Royal Scottish Aboricultural Society* 19, 52-65.

Rawlings, G.B. (1959) Problems of forest entomology in exotic forests in New Zealand. *Proceedings of the Tenth International Congress of Entomology, Montreal*, 1956, 241-246. New Zealand forestry research notes No 22. New Zealand Forest Service.

Valentine, E.W. (1970) A list of the phytophagous Hymenoptera in New Zealand. *The New Zealand entomologist* 4, 52-62.

Paropsis charybdis Stål, eucalyptus tortoise beetle (Coleoptera: Chrysomelidae)

J. BAIN and M.K. KAY

Pest Status

Paropsis charybdis Stål is the most serious defoliator of *Eucalyptus* spp. in New Zealand and has been the major constraint to the planting of commercially important species. Both the adults and larvae are voracious feeders. The larvae feed on the young foliage, whereas the adults are more adaptable and often feed on older leaves and the foliage of normally non-preferred *Eucalyptus* spp. hosts. Oviposition, and consequent larval damage, is largely restricted to eucalypts in the sub-genus *Symphyomyrtus*, Section Maidenaria (after Pryor & Johnson 1971), e.g. *Eucalyptus viminalis* La Billardière, *E. globulus* La Billardière and *E. nitens* (Deane & Maiden) Maiden. These eucalypts support both larval and adult *P. charybdis* and are prone to severe defoliation every year. Oviposition on other species is not common and when it does occur the larvae have long developmental times and high mortality.

Heavy defoliation results in a crown devoid of current foliage and a proliferation of juvenile foliage on the main stem and larger branches. Repeated defoliation may result in crown die-back, and complete defoliation over two consecutive years can cause the death of young trees. Heavily defoliated older trees may survive indefinitely in a moribund condition. These problems have been avoided as far as possible by planting species of eucalypts that are not favoured by *P. charybdis*.

Background

This Australian chrysomelid, first recorded in the Port Hills, near Christchurch in 1916 (Clark 1930) was known in New Zealand as *Paropsis dilatata* Erichson until Selman's (1963) reappraisal of the genus. Clark (1938) speculated that it entered the country as eggs or young larvae on small eucalypt plants, or as hibernating adults under the bark of imported Australian hardwoods. It moved steadily through the South Island, and did not reach the North Island until 1956. Its spread has been detailed by White (1973), and it is now present wherever eucalypts are grown.

The pentatomids *Cermatulus nasalis* (Westwood) and *Oechalia schellembergii* (Guérin-Méneville) and the German wasp *Vespula germanica* (F.) are predators of *P. charybdis* in New Zealand (Valentine 1967), but Edwards & Suckling (1980) and Styles (1970) concluded that they were ineffective controls. Styles (1970) suggested that birds and hedgehogs may also feed on *P. charybdis* pupae in the soil.

In Australia *P. charybdis* is very rare, and its numbers are presumably regulated by natural enemies and other factors (Edwards & Suckling 1980). Larval parasitoids (Tachinidae and Braconidae) and an egg parasitoid (Pteromalidae) of *Paropis* spp. were recorded there in the 1930s and unsuccessful attempts were made to introduce them into New Zealand. The 1960s and 1970s saw much increased interest in New Zealand in eucalypts for pulp and sawn timber, and this stimulated further interest in biological control of *P. charybdis*. Unsuccessful attempts were again made with tachinids and a braconid. In the late 1970s Elliott & de Little (1980) reported that the coccinellid *Cleobora mellyi* Mulsant was commonly associated with the eucalypt defoliator *Chrysophtharta bimaculata* (Oliver) (Chrysomelidae) in Tasmania and suggested that it might be useful as a predator of *P. charybdis* in New Zealand (Forest Research Institute (FRI) files). Imports were made, rearing was successful but establishment

has been limited to one area. In 1987 G. Tribe, working in Perth, Western Australia, on biological control agents of *Trachymela tincticollis* (Blackburn) (Chrysomelidae), a recent introduction into South Africa, informed the Forest Research Institute (FRI) that he had laboratory cultures of the pteromalids *Neopolycystus insectifurax* (Girault) (the species unsuccessfully imported into New Zealand in the 1930s) and another egg parasitoid *Enoggera nassaui* (Girault). His offer to supply these insects was accepted, rearing at Rotorua was successful, and liberation is continuing.

Importations, Releases and Recoveries

The importation of biological control agents for *P. charybdis* has gone through three distinct periods of activity involving three different organisations. The earliest work was done in the 1930s at the Cawthron Institute, Nelson, when A.F. Clark received paropsine egg and larval parasitoids from A.L. Tonnoir in Canberra. Nothing was done for another 30 years, when prompted mainly by pressure from the New Zealand Farm Forestry Association, both the DSIR, Nelson and the FRI received small consignments of larval parasitoids from Australia. The matter was then delayed for another ten years until a large private forestry company precipitated more work by sending a staff member to Australia to search for parasitoids. Since then biological control work on *P. charybdis* has gone on at the FRI more or less continuously. Importations and liberations are listed in Table 49.1. It is noteworthy that only one of the introduced biological control agents was reared specifically from *P. charybdis* in Australia; all others were from closely related species.

Meteorus sp. (Hymenoptera: Braconidae)

Seven cocoons of this larval parasitoid were sent from Canberra by Tonnoir in September 1932, but it not known what happened to them (FRI files).

Table 49.1 Biological control programmes against *Paropsis charybdis*. E = established.

Programme Date	Reference	Control Agent	Releases	Established /Recovered
1934-35	Clark 1938	*Froggattimyia tillyardi* Malloch	No	
	FRI files	*Neopolycystus insectifurax* Girault	No	
		Aridelus sp.	No	
1963	FRI files	*Aridelus* sp.	No	
1964	FRI files	*Froggattimyia* sp.	No	
		Aridelus sp.	No	
1973-74	FRI files	*Froggattimyia tillyardi* plus a few *Paropsivora* sp.	No	
		Aridelus sp.	No	
1974-75	FRI files	*Froggattimyia tillyardi* plus a few *Paropsivora* sp.	Yes	
1977-80	Bain *et al.* 1984 FRI files	*Cleobora mellyi* Mulsant	Yes	E
1987	FRI files	*Neopolycystus insectifurax*	Yes	
		Enoggera nassaui (Girault)	Yes	E

Aridelus sp. (Hymenoptera: Braconidae)

In February 1934 the Cawthron Institute received a small but unspecified number of late instar larvae of various *Paropsis* spp. from Tonnoir in Canberra. These yielded 'several ichneumonid larvae' (sic). The fate of these was not recorded (FRI files). In January 1935 ten braconid cocoons were received from the same source. These braconids had been reared from *Paropsis atomaria* Olivier. Three adults emerged but their fate is unrecorded (FRI files).

In May 1963 the FRI received approximately 120 *Aridelus* sp. cocoons ex *P. atomaria* from P.B. Carne, Canberra. The consignment was heavily hyperparasitised (27% of the cocoons yielded a pteromalid, *Perilampus* sp.) and only three braconids emerged. Laboratory parasitism of *P. charybdis* was not attempted (FRI files). In February 1964 the DSIR received a very small consignment of *Aridelus* sp. cocoons from Canberra. The only emergences were a very few *Perilampus* sp.

Between November 1973 and January 1974 the FRI received 496 *Aridelus* sp. cocoons obtained from *P. atomaria* in Australia but nothing emerged (FRI files).

Froggattimyia tillyardi Malloch, *Froggattimyia* spp. and *Paropsivora* spp. (Diptera: Tachinidae)

In February 1934 the Cawthron Institute received a small but unspecified number of late instar larvae of various *Paropsis* spp. from Australia and 'a quantity of tachinid puparia' resulted (FRI files). In March a further 24 tachinid puparia were received and it was recorded that 10 adults had emerged from the earlier consignment and fed in the laboratory. About 29 tachinid puparia were sent in January 1935 and in December Clark reported that a number of tachinids had been reared (FRI files). Apparently two distinct species were present in all consignments. It is not known if parasitism of *P. charybdis* in the laboratory was attempted. There were no field releases (FRI files).

In February 1964 DSIR received a small consignment of *Froggattimyia* spp. pupae from Carne in Canberra bred from *Chrysophtharta bimaculata* (Olivier). It is not recorded how many (if any) tachinids emerged. The consignment was very heavily hyperparasitised by a *Mesochorus* sp. (Ichneumonidae).

During the summer of 1973-74 the FRI received 5,435 tachinid puparia of which 58% yielded insects. Just over half were tachinids, mostly *Froggattimyia tillyardi* with a few *Paropsivora* sp., and the rest the hyperparasitoids *Mesochorus* sp. (46%) and *Perilampus* sp. (6%). About 8,000 *P.charybdis* larvae in various stages of development were exposed to the tachinids but only three adult flies were bred. No field releases were made.

In the 1974-75 season 10,632 tachinid pupae were sent from Australia to the FRI. Seventy percent eclosed. Of these 66% gave tachinids (nearly all *F. tillyardi* plus a few *Paropsivora* sp.), 31% *Mesochorus* sp. and 3% *Perilampus* sp. Over 10,000 *Paropsis* larvae were exposed to the emerged tachinids but only 49 F1 flies were reared. When it was realised that insufficient F1 specimens were going to be reared for worthwhile field releases it was decided to also liberate flies emerging from the imported pupae and which were surplus to laboratory requirements. Two releases of healthy, well-formed, three-week old *F. tillyardi* were made in the Whakamaru Block of NZFP Forests Ltd estate (south of Tokoroa) adjacent to a 10 year old stand of *Eucalyptus ovata* La Billardière and *E. radiata* Sieber which had a large population of *P. charybdis*. The first release of 480 was made in January 1975 and in February there was a further release of 225. During the following spring and summer (1975-76) monthly samples of 100 *P. charybdis* larvae were collected from the area and reared in the laboratory but no tachinids were recovered (FRI files), and none have emerged from the very many larvae that have been brought in to the laboratory from this and other localities over the past 10 years. It is concluded that the tachinids did not establish.

Cleobora mellyi Mulsant (Coleoptera: Coccinellidae)

Adult *C. mellyi* were first imported into New Zealand by FRI from Tasmania in October 1977. About 600 *C. mellyi* adults were collected by D. de Little and H.J. Elliott from hibernation sites (under the bark of dead, standing *Nothofagus* spp.) and sent to Rotorua.

A few (ca. 20) F1 adults were produced in the laboratory using *P. charybdis* eggs and small larvae as food for the *C. mellyi* larvae (Bain *et al.* 1984). Plans to bring in more *C. mellyi* adults from Tasmania in 1978 were thwarted when the beetles left their hibernation sites earlier than anticipated. However about 400 overwintered adults were imported in August 1979 and improved rearing techniques (Bain *et al.* 1984) meant that nearly 3,000 F1 adults were released in eucalypt plantations in the central North Island (see Table 49.2).

In August 1980 a consignment of about 400 adults was received from Tasmania to augment those held over from the previous season's rearing. During October-November 1980 nearly 2,000 adults were released in NZFP Forests Ltd eucalypt plantations near Tokoroa. A further 830 reared beetles were overwintered by using a modified beehive at the FRI and this containing the beetles was placed in a eucalypt plantation near Tokoroa in September 1981. During November and December 1981, *C. mellyi* larvae were found in the field in the vicinity of the release site feeding on *P. charybdis* eggs and young larvae but they have never been found again in this area. More releases were made in September 1982 (with a beehive being provided as an artificial overwintering site) near Tokoroa but no recoveries were made either from the beehive in winter or from the surrounding trees the following spring and summer.

In August 1983 nearly 3,000 adult *C. mellyi* were liberated (ex a beehive) in a small eucalypt plantation at Maori Bay in the Marlborough Sounds in the South Island. A few adults have been recovered every year since then and in 1987 an overwintering congregation of 'several dozen' adults were found under the bark of a dead *Eucalyptus* sp. (R. Lambert pers. comm.). It is concluded that *C. mellyi* is established at Maori Bay.

Table 49.2 Details of *Cleobora mellyi* releases

Date	Location	Number beetles released
Oct. 1979	NZFP Forests, Kauri Road, near Tokoroa	2724
Feb. 1980	NZFP Forest, Kauri Road, near Tokoroa	315
Mar. 1980	Whakarewarewa Forest, Rotorua	88
Oct. 1980	NZFP Forests, Kaahu Farm, south of Tokoroa	914
Nov. 1980	NZFP Forests, Kaahu Farm, south of Tokoroa	995
Sep. 1981	NZFP Forests, Kauri Road, near Tokoroa	830
Sep. 1982	NZFP Forests, Kaahu Farm, south of Tokoroa	1542
Aug. 1983	Maori Bay, Marlborough Sounds	2849
Aug. 1983	Christchurch	200
Oct. 1987	Rotoehu, Bay of Plenty	200

Neopolycystus insectifurax Girault (Hymenoptera: Pteromalidae)

In March 1934 the Cawthron Institute received a small consignment of eggs of *P. atomaria* collected in the field in Australia by Tonnoir (Clark 1938, FRI files). Two further small consignments were received from the same source in December 1934, another in January 1935, and a final one in March 1935. Clark (1938) states that 'although several consignments of eggs were received, no parasites were obtained'; however perusal of correspondence between Clark and Tonnoir reveals that Clark did rear five *Neopolycystus* adults from the first consignment and one of the females successfully parasitised *P. charybdis* eggs in the laboratory. Only one parasitoid emerged from the third consignment. No liberations were made (FRI files).

In June 1987 the FRI received approximately 400 adult *N. insectifurax* from G. Tribe, Perth, Western Australia. These were successfully cultured in quarantine and field releases of progeny (Table 49.3) were made in 1987-88. So far no recoveries have been made.

Table 49.3 Releases of *Paropsis charybdis* egg parasitoids

Locality	*E. nassaui* (Girault)	*N. insectifurax* Girault	Date	Numbers (approx.)
NELSON				
Collingwood	++	++	Nov. 87	1300*
Golden Downs	++	++	Nov. 87	1300*
Richmond	++	++	Nov. 87	1300*
SOUTHLAND				
Longwoods	++		Nov. 87	1300
Tapanui	++		Nov. 87	1300
Kaitangata	++		Nov. 87	1300
CANTERBURY				
Chertsey	++	++	Jan. 88	2000*
Rolleston	++		Jan. 88	2000
BAY OF PLENTY				
Kaingaroa	++	++	Feb. 88	3000*
Maketu	++	++	Feb. 88	3000*
WAIKATO				
NZFP Forests	++	++	Feb. 88	3000*
near Tokoroa	++	++	Mar. 88	1600*

*Totals include equal numbers of both species.

Enoggera nassaui (Girault) (Hymenoptera: Pteromalidae)

Approximately 80 *E. nassaui* adults were received at the FRI from Tribe in Perth in August 1987. The species was successfully cultured and field releases were made in 1987-88 (Table 49.3). *P. charybdis* eggs parasitised by *E. nassaui* have been found in the field at Maketu (Bay of Plenty) and Collingwood (Nelson). In October 1988 *E. nassaui* adults were observed ovipositing in *P. charybdis* eggs at Collingwood (R. Nicholls pers.comm) so this species is definitely established at least in this area.

Evaluation

Neopolycystus insectifurax and *Enoggera nassaui*

Both these egg parasitoids regularly achieved 100% parasitism of *P. charybdis* eggs in the laboratory. *E. nassaui* averaged 90% survival to eclosion and *N. insectifurax* 60%. Sex ratios for *E. nassaui* were often as high as 1 male:7 female but *N. insectifurax* rarely produced more than 1:3. Both *P. charybdis* and *E. nassaui* have the same developmental threshold temperature (i.e. 9°C) but *N. insectifurax* is somewhat higher at 12.5°C. Both parasitoids have generation times of ten days at a constant 25°C.

Over most of New Zealand *P. charybdis* has two distinct summer generations, with the first peaking in November when mean temperatures approximate 13°C and the second in February with mean temperatures about 17°C. In warmer, coastal areas all developmental stages of *P. charybdis* can be found throughout the year. Ideally this means that the two parasitoids should complement each other with *E. nassaui* being the dominant species early in the season and *N. insectifurax* predominating later. At higher temperatures in the laboratory competitive exclusion favours the more aggressive *N. insectifurax* which has a greater production of offspring from multiple species parasitism of *P. charybdis* eggs.

Cleobora mellyi

Cleobora mellyi is certainly a voracious feeder on *P. charybdis* eggs but these are not an essential food in the sense of Hodek (1973). *C. mellyi* does not mate and reproduce readily on a diet solely comprising *P. charybdis* eggs, and alternative food in the form of psyllids etc. is necessary to achieve good fecundity and survival (Bain *et al.* 1984). Its failure to establish in the central North Island is not easily explained. This area and the origin of the *C. mellyi* imported into New Zealand, the Florentine Valley, Tasmania, are climatically very similar and at first it was thought that a lack of suitable overwintering sites was the likely cause. In Tasmania *C. mellyi* commonly overwinters under the loose bark of dead, standing *Nothofagus* spp. trees and these are lacking in New Zealand eucalypt plantations. However, *C. mellyi* has been found overwintering under the loose bark of a dead *Eucalyptus* sp. in the Marlborough Sounds so where these exist in the North Island a lack of suitable overwintering sites seems a less plausible reason for non-establishment there.

Conclusions

The lack of specific parasitoids and predators of *P.charybdis* is seen as a major obstacle to the successful biological control of this insect. All attempts to date would have to be classified as 'opportunistic' in that they were not preceded by detailed study of the host's biology either in Australia or, until recently, in New Zealand. The two pteromalid egg parasitoids released in 1987-88 show some promise and their dispersal should be rapid if it follows experience in South Africa where an introduced, undescribed species of *Enoggera* spread 400 km on prevailing winds in one season (G. Tribe pers. comm.). However, the unknown overwintering abilities and the limited host range available in New Zealand, both in species and time casts some doubts on the self-perpetuation of the parasitoid populations in inland areas. *Enoggera nassaui* does, however, show considerable promise for inundative releases. Major releases of *E. nassaui* and *N. insectifurax* are planned for the 1988-89 season. No further work is planned on *C. mellyi*. If any further work on the biological control of *P. charybdis* is considered, and this will depend on the success of the pteromalid egg parasitoids, it should be preceded by a study of the bionomics of *P. charybdis* in Australia.

Literature Cited

Bain, J.; Singh, P.; Ashby, M.D.; Van Boven, R.J. (1984) Laboratory rearing of the predatory coccinellid *Cleobora mellyi* (Col.: Coccinellidae) for biological control of *Paropsis charybdis* (Col.: Chrysomelidae) in New Zealand. *Entomophaga* 29, 237-244.

Clark, A.F. (1930) *Paropsis dilitata* Er. in New Zealand. Preliminary account. *New Zealand journal of science and technology* 12, 114-123.

Clark, A.F. (1938) A survey of the insect pests of eucalypts in New Zealand. *New Zealand journal of science and technology* 19, 750-761.

Edwards, P.B.; Suckling, D.M. (1980) *Cermatulus nasalis* and *Oechalia schellenbergii* (Hemiptera: Pentatomidae) as predators of eucalyptus tortoise beetle larvae, *Paropsis charybdis* (Coleoptera: Chrysomelidae), in New Zealand. *New Zealand entomologist* 7, 158-164.

Elliott, H.J.; de Little, D.W. (1980) Laboratory studies on predation of *Chrysophtharta bimaculata* (Olivier) (Coleoptera: Chrysomelidae) eggs by the coccinellids *Cleobora mellyi* Mulsant and *Harmonia conformis* (Boisduval). *General and applied entomology* 12, 33-36.

Forest Research Institute, file E86.

Hodek, I. (1973) Biology of the Coccinellidae. W. Junk, The Hague. 260 pp.

Pryor, L.D.; Johnson, L.A.S. (1971) A classification of the eucalypts. The Australian National University, Canberra. 102 pp.

Selman, B.J. (1963) A reappraisal of the genus *Paropsis* Ol. (Chrysomelidae, Coleoptera), with particular reference to the species introduced into New Zealand. *Annals and magazine of natural history* (13)6, 43-47.

Styles, J.H. (1970) Notes on the biology of *Paropsis charybdis* Stal (Coleoptera: Chrysomelidae). *New Zealand entomologist* 4, 103-111.

Tanton, M.T.; Epila, J.S.O. (1984) Parasitization of larvae of *Paropsis atomaria* Ol. (Coleoptera: Chrysomelidae) in the Australian Capital Territory. *Australian journal of zoology* 32, 251-259.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

White, T.C.R. (1973) The establishment, spread and host range of *Paropsis charybdis* Stal (Chrysomelidae) in New Zealand. *Pacific insects* 15, 59-66.

Phyllonorycter messaniella (Zeller), oak leaf-miner (Lepidoptera: Gracillariidae)

W.P. THOMAS and R.L. HILL

Pest Status

The oak leaf-miner, *Phyllonorycter* (= *Lithocolletis*) *messaniella* (Zeller) was first recorded in New Zealand from *Quercus robur* L. (= *Q. pedunculata* Ehrhart) growing in Gisborne in February 1951 by Wise (1953a). He provided a brief description of the moth and its known distribution at the time, namely Britain, Ireland, Central and Southern Europe, South West Asia and North Africa.

By 1954 the species had spread through much of the North Island and as far south as Nelson Province in the South Island (Wise 1954). Oak leaf-miner continued to spread rapidly and by 1958 it was present throughout most of New Zealand and had become abundant wherever suitable host plants occurred (Given 1959).

This species was first reported to have become established in the Australian Capital Territory and New South Wales by Common (1976). It spread rapidly into other eastern states, (New 1981). By 1977 the species was also known to have become established on Norfolk Island in the South Pacific (Smithers 1977).

In New Zealand, oak leaf-miner quickly became a major pest of several species of deciduous and evergreen oaks and other ornamental trees. Wise (1953b) reported host species in the following genera: *Quercus*, *Fagus*, *Nothofagus*, *Castanea*, *Betula*, *Carpinus*, *Parrotia*, *Liquidambar*, *Carya*, and *Feijoa*. The following year Wise (1954) reported two new rosaceous hosts, *Malus sylvestris* L. (apple) and *Prunus* sp. (ornamental cherry). Additional hosts are provided by Wise (1958), Given (1959) and Spiller & Wise (1982).

The biology of oak leaf-miner in Europe is discussed in detail by Delucchi (1958). Given (1959) and Swan (1973) give an outline of the life history of *P. messaniella* in New Zealand and discuss mortality factors.

The linear mine is expanded during the first three (or four according to Swan (1973)) sap-feeding, larval instars. The body of the sap-feeding larva is dorsally flattened. A complete change in the body form occurs when larvae moult to the fourth instar and become tissue feeders with hypognathus mouthparts and cylindrical bodies, typical of most lepidopterous larvae. These feed selectively on the spongy parenchyma of the leaf within the confines of the mine formed by third instar larvae. Fourth instar larvae spin a layer of silk over the lower walls of the mines (the epidermis) which contracts with drying to form an epidermal fold, the blotch or tentiform mine, typical of many leaf-mining species. *P. messaniella* pupates within a rough cocoon within the mine, but just prior to moth emergence the pupa forces its way partially out of the lower epidermal covering of the blotch mine.

Swan (1973), found that *P. messaniella* completed three generations annually in New Zealand, two on deciduous hosts and one on evergreen oaks, with spring, summer and autumn emergence periods. This contrasts with the six or seven generations reported by Delucchi (1958) and Given (1959) but agrees with New (1981) and others.

P. messaniella has no diapausing stage. This is in contrast to several other species recorded on oaks (Delucchi 1958) and *P. blancardella* (F.) on apple in Canada (Pottinger & LeRoux 1971). Mated female moths of the spring generation oviposit mainly on deciduous host species and complete two summer generations. The autumn moths oviposit on evergreen oaks. Given (1959) found no evidence of survivors on fallen leaves from deciduous oaks during the winter months.

Following the early records of establishment of the oak leaf-miner in New Zealand the number of blotch mines reported on various hosts in Nelson ranged up to 40 per leaf (Given 1959). When numerous, the mining larvae caused serious damage, premature browning, and the loss of foliage on many host trees. Serious damage occurred on many oaks and other ornamental trees in parks and reserves throughout the country (DSIR files). Chemical methods for the control of oak leaf-miner were considered impracticable (Given 1959).

Background

The spread and host range of oak leaf-miner in New Zealand were recorded by Wise (1953a, 1953b, 1954, 1955, 1958). The high incidence of mines on exotic hosts together with the attack on apple and indigenous forest species such as *Nothofagus* spp. were seen as a major threat to the fruit-growing and forestry industries (Given 1959). Given (1959) discussed the effects of the *P. messaniella* population pressure on various hosts and the two major areas of population mortality. These included reaction by the host plant leaf to larval feeding activity, and mortality resulting from parasitism by the eulophid parasitoid, *Pnigalio pectinicornis* (L.), which probably entered the country with its host. Neither of these mortality factors was considered important enough to contain the host population during early season, although the parthenogenetic *P. pectinicornis* was consistently present. The importance of predators on *Phyllonorycter messaniella* in New Zealand is unknown, but a number are known to attack *P. blancardella* in Canada (Pottinger & LeRoux 1971).

In 1955, Entomology Division, DSIR, requested CIBC to conduct a survey of the parasitoids of oak leaf-miner in Europe, where recorded levels of infestation by the pest were reported to be very much lower. V.L. Delucchi conducted the survey and research in Europe, and this is fully documented (Delucchi 1958). Investigations commenced in autumn 1955 and continued until spring 1957. These concentrated on the south of Switzerland and Italy, although additional material was collected from Britain and Sardinia.

In Europe some 20 species of parasitoids including some partial hyperparasitoids were collected. Two primary, endoparasitic species, a braconid known then as *Apanteles circumscriptus* (Nees) and a eulophid, *Achrysocharoides* (= *Enaysma*) *splendens* (Delucchi) were selected for importation into New Zealand. These two species were considered by Delucchi to be important parasitoids, which were active at different periods of the year. Since then, Nixon (1973) has revised the *circumscriptus* group of the genus *Apanteles*, which has relevence to the importations made (see Evaluation).

Importations, Releases and Recoveries

Delucchi air-mailed cocoons labelled as *A. circumscriptus* to New Zealand with an agar-sugar-honey jelly mix supplied as food for the emerging parasitoids. En-route to New Zealand, a journey of six or more days, the mortality of the parasitoids was less than 1%.

Consignments of parasitoids named as *Apanteles circumscriptus* and *Enaysma splendens* were received in New Zealand in March/April 1957 and October/November 1957 respectively. Details of the consignments of the two parasitoids are provided by Given (1959). A total of 806 females and five males referred to by the writer as *A. circumscriptus* group originating from Italy, successfully emerged from the 954 pupal cocoons received.

A mixture of 32 individual hyperparasitoids and competing species emerged from the *A. circumscriptus* group consignments and 193 from the *Achrysocharoides splendens* shipments. These were destroyed in quarantine. After identification adults of both imported parasitoids were released into field cages.

Given (1959) described the method of liberating the parasitoids initially into cages enclosing *P. messaniella*-infested leaf clusters of evergreen oaks, *Q. ilex* L. and *Q. suber* L. in Nelson.

Cages were removed after four to five days and some hosts checked for parasitism levels. For *Apanteles circumscriptus* group, parasitism levels on cage-samples ranged between 0% and 50% with second instar host larvae being the most heavily attacked. Later sampling in the winter and spring of 1957 confirmed the establishment and slow spread of *A. circumscriptus* group (Given 1959).

A comprehensive distribution programme for this parasitoid followed during the next two years, when large numbers were sent to provincial Directors of Parks and Reserves, DSIR and Ministry of Agriculture and Fisheries personnel for distribution in many districts in New Zealand.

For *Achrysocharoides splendens*, 352 individuals were reared from the 626 pupae collected in Switzerland. This species was initially released in a similar way onto *Quercus cerris* L. in Nelson. A sampling programme confirmed that *A. splendens* also established following its initial release. Because this species overwinters in pupal diapause, the leaves that contained *A. splendens* pupae in the winter of 1958 were transferred to an oak plantation at Stoke (Nelson) where it was certain that the leaves would remain undisturbed (Given 1959). The further distribution of *A. splendens* was similar to that for *Apanteles circumscriptus* group. In both instances adults emerging from infested leaf clusters in a small room were collected directly into glass cylinders using a modified hand-held vacuum cleaner. Large numbers were handled in this way for distribution.

Evaluation

Initial confirmation of the establishment of the two parasitoids was obtained by Given in Nelson soon after their release (Given 1959). He noted the ecological displacement of *Pnigalio pectinicornis* which was confirmed in later research (DSIR files, Swan 1973). As a result, the population of *P. pectinicornis* declined very rapidly in Nelson during the period 1958–60 in Nelson, compared with numbers observed prior to 1958. At the same time, the *P. pectinicornis* population commenced to produce a high proportion of males which had not been observed previously during the period 1951-1958, when only females were produced parthenogenetically (DSIR files).

In Nelson, the population levels of oak leaf-miner declined rapidly during the years following successful establishment of *Achrysocharoides splendens* and especially *Apanteles circumscriptus* group. By the mid-1960s the host range of *Phyllonorycter messaniella* had also reduced and the species could not be found in Nelson on native beech *Nothofagus* spp., or apple trees. Evaluations of the efficacy of the two purposely-introduced parasitoids in New Zealand were made by Swan (1973) who concentrated his investigation in Christchurch. He noted the incidence of oak leaf-miner damage in the lower crown of deciduous oak trees near evergreen oaks was 6.3 mines per leaf. However, on some deciduous oaks the incidence of mines was negligible. The relative number and density of evergreen oaks and deciduous oaks were considered by Swan (1973) to be important in the population dynamics of oak leaf-miner, with cannibalism an important mortality factor in high leaf infestations. On deciduous oaks, total parasitism ranged from 30% to 80% and *A. circumscriptus* group was the most abundant parasitoid. *Achrysocharoides splendens* was of almost equal importance where low host populations occurred. *Pnigalio pectinicornis* had been almost completely displaced by the other two parasitoids. Swan (1973) also compared the levels of oak leaf-miner infestation in Nelson and he found that the number of mines per leaf on *Q. robur* had declined from more than 40 mines per leaf prior to the release of parasitoids, to around 2.3 mines per leaf in 1969-70.

Both Common (1976) and New (1971) reported the incidence of parasitism of oak leaf-miner by native parasitoids in Australia. These species have not been recorded in New Zealand. Parasitoids recorded in Europe on *Phyllonorycter messaniella* by Delucchi (1958) are not found on *P. blancardella* in North America.

Although oaks and various other ornamental hosts in New Zealand show levels of infestation by oak leaf-miner which are much higher than those reported in Europe (Delucchi 1958), there is little evidence that these levels are damaging. Swan (1973) considered that additional introductions of parasitoids would be advantageous but this is unlikely to occur.

In 1978, two consignments totalling 200 field collected *Apanteles* spp. cocoons were sent from Auckland to Canada where they were to be established for biological control of *Phyllonorycter blancardella*. Later identification of specimens indicated that the first shipment contained *Apanteles arisba* Nixon only and the second shipment *Apanteles bicolor* (Nees) alone. *A. circumscriptus* was not present (Laing & Heraty 1981). If these identifications are correct, the consignments obtained from Europe in 1957 presumably contained a mixture of *Apanteles* spp. The true identity of the parasitoids attacking oak leaf-miner in New Zealand remains to be resolved. Until then, they should be referred to as *A. circumscriptus* group. Only two female *A. bicolor* survived importation into Canada. From these parents, the parasitoid has become established and is spreading rapidly (Laing 1984).

Conclusions

The introduction of the two parasitoids of oak leaf-miner, *Apanteles circumscriptus* group and *Achrysocharoides splendens*, into New Zealand followed the accidental establishment of the pest on an extended range of hosts. This programme is probably one of the best examples of successful classical biological control of a pest in this country. The seriousness of the damage caused by the pest when free of effective controlling agents was well documented as the population explosion occurred. However, oak leaf-miner was very effectively and rapidly reduced to insignificant levels by the introduction of the two parasitoids and these have provided effective control from the 1960s to the present day.

Literature Cited

Common, I.F.B. (1976) Oak leaf-miner *Phyllonorycter messaniella* (Lepidoptera: Gracillariidae) established in Australia. *Journal of the Australian Entomological Society* 15, 471-473.

Delucchi, V.L. (1958) *Lithocolletis messaniella* Zeller (Lep. Gracillariidae): analysis of some mortality factors with particular reference to its parasite complex. *Entomophaga* 3, 203-270.

DSIR, Entomology Division, file BC 1/4.

Given, B.B. (1959) Biological control factors influencing populations of oak leaf-miner, *Lithocolletis messaniella* Zeller, in New Zealand including the introduction of parasites. *New Zealand journal of agricultural research* 2, 124-133.

Laing, J.E. (1984) *Phyllonorycter blancardella* (F.), spotted tentiform leafminer (Lepidoptera: Gracillariidae) Pp. 69-71 in Kelleher, J.S.; Hulme, M.A. (eds.). Biological control programmes against insects and weeds in Canada 1969-1980. Commonwealth Agricultural Bureaux, Slough.

Laing, J.E.; Heraty, J.M. (1981). Establishment in Canada of the parasite *Apanteles pedias* Nixon on the spotted tentiform leafminer *Phyllonorycter blancardella* (Fabr.). *Environmental entomology* 10, 933-935.

New, T.R. (1981) The oak leaf-miner, *Phyllonorycter messaniella* (Zeller) (Lepidoptera: Gracillariidae), in Melbourne. *Australian journal of zoology* 29, 895-905.

Nixon, G.E.J. (1973) A revision of the north-western European species of the *vitripennis*, *pallipes*, *octonarius*, *triangulator*, *fraternus*, *formosus*, *parasitellae*, *metacarpalis* and *circumscriptus* groups of *Apanteles* Förster (Hymenoptera: Braconidae. *Bulletin of entomological research* 63, 169-228.

Pottinger, R.P.; LeRoux, E.J. (1971) The biology and dynamics of *Lithocolletis blancardella* (Lepidoptera: Gracillariidae) on apple in Quebec. *Memoirs of the Entomological Society of Canada* 77, 437 pp.

Smithers, C.N. (1977) The oak leaf-miner *Phyllonorycter messaniella* Lepidoptera Gracillariidae established on Norfolk Island, South Pacific Ocean. *Australian entomological magazine* 4, 16.

Spiller, D.M.; Wise, K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR bulletin* 231, 260 pp.

Swan, D.I. (1973) Evaluation of biological control of the oak leaf-miner *Phyllonorycter messaniella* (Zell.) (Lep., Gracillariidae) in New Zealand. *Bulletin of entomological research* 63, 49-55.

Wise, K.A.J. (1953a) The oak leaf-miner *Lithocolletis messaniella* Zeller in New Zealand. *New Zealand science review* 11, 85.

Wise, K.A.J. (1953b) Host plants of *Lithocolletis messaniella* Zeller (Lepidoptera: Gracillariidae) in New Zealand. *New Zealand journal of science and technology* 35, 172-174.
Wise, K.A.J. (1954) Records and observations of New Zealand Lepidoptera. *New Zealand entomologist* 1 (4), 27-30.
Wise, K.A.J. (1955) Notes on New Zealand Lepidoptera. *New Zealand entomologist* 1 (5), 13.
Wise, K.A.J. (1958) Notes on insect pests 1957-58. *New Zealand entomologist* 2, 12-14.

Pineus laevis (Maskell), pine twig chermes or pine woolly aphid (Homoptera: Adelgidae)

R. ZONDAG and M.J. NUTTALL

Pest Status

Clark (1932) reported that infestation by the sap-sucking insect *Pineus laevis* (Maskell) could result in shortening of needles, malformation, defoliation, and even death of the various species of exotic pine (*Pinus*) grown in New Zealand. However the most extreme effects have not been seen in recent times and the insect is now of little economic importance (Zondag 1977).

In young pine stands infested trees usually occur scattered amongst others free from attack (Miller & Clark 1935). After a dry summer there may be an increase in the number and severity of attacks. Such populations decline or terminate in spring, although the white flocculent waxy material produced as a covering by the insect may persist for some time longer. In drier areas, or where trees are under stress, infestations may persist and growth losses result. Under such conditions the insects often do not confine their attention to twigs and branches but may also occur on the main stem.

Background

Pineus laevis was first noticed in New Zealand in about 1880 (Maskell 1885), and its origin is believed to be western North America (Zondag 1977). Predatory insects (Berothidae, Hemerobiidae, and Syrphidae) were present, but their occurrence was infrequent (Clark 1932). Therefore two predators (Chamaemyiidae and Hemerobiidae) from the U.K. and one from Australia (Coccinellidae) were imported by Miller & Clark (1935) (Forest Research Institute (FRI) files) at the Cawthron Institute, Nelson. A reference to *Chrysopa* spp. from North America (Clausen 1978) is uncorroborated.

Since being first described by Maskell (1885) as *Kermaphis pini* var. *laevis* this insect has been referred to by several names in New Zealand, including *Pineus pini* (Gmelin) and *P. strobi* (Hartig). Neither of these insects occurs here. The name *P. boerneri* Annand has also been used, but this is a synonym of *P. laevis* (Eastop 1966).

Importations, Releases and Recoveries

Leucopis tapiae Blanchard (Diptera: Chamaemyiidae)

In 1932 six consignments of *Leucopis* sp. larvae from Farnham House Parasite Laboratory, U.K. arrived by sea in the winter months of April, May and June (Clark 1936, Miller & Clark 1935). Some had pupated during transit, but larval mortality had been high, presumably through cannibalism. Many adults emerging in June-August died in the cold weather. Laboratory and insectary rearing on *Pinus radiata* infested with *Pineus laevis* failed, and all available adults were released during May-August in the Nelson district. There were eight liberations totalling 145 flies, sex not determined. Miller & Clark (1935) also stated that a single liberation of 25 flies was made in September at Taupo in the North Island, but no year is mentioned and it is possible that this release occurred in 1934 since it is only in this year that liberation at Taupo is mentioned by Clark (1936). A smaller unspecified number

of *Leucopis* sp. was imported in 1934 and, as well as at Taupo, liberation was once more made in the Nelson district (Clark 1936, FRI files).

Miller & Clark (1935) reported that a few eggs and larvae had been found in field collected twig samples taken in August and September 1932 (FRI files), the year of the initial releases. Many attempts at field recovery were made subsequently but it was concluded by 1935 that establishment had failed or succeeded to a very limited extent (Miller & Clark 1935). The first records of establishment came in 1954 from Whakarewarewa in the Bay of Plenty and Balmoral in North Canterbury (FRI files). Subsequently this predator was found in many collections from various localities in both islands.

There has been some confusion over the identity of the introduced chamaemyiid. In fact Miller & Clark (1935) thought that at least two species were present in the 1932 consignments. Whether or not this was so is unknown since there are apparently no voucher specimens from the original imports in any New Zealand collection. Papers by Miller & Clark (1935) and Clark (1936) simply refer to the predator as *Leucopis* sp., but contemporaneous unpublished reports by Clark (FRI files) and an annual report of the Cawthron Institute (1935) states it to be *Leucopis obscura* Haliday. This name appeared in Miller (1950), and was used by Rawlings (1953) and subsequent authors. The identity of the predator was clarified by J.F. McAlpine when he determined specimens from New Zealand as *Leucopis* (*Neoleucopis*) *tapiae* Blanchard (McAlpine 1971, FRI files). This species had originally been described from Argentina where it had been introduced with nursery stock from Europe.

Hemerobius stigma Stephens (Neuroptera: Hemerobiidae)

In 1932 adults of *H. stigma* were sent from the U.K. at the same time as the *Leucopis* sp. No work was attempted with the few that survived the journey, as there was a possibility that the larvae of this lacewing could feed on those of the chamaemyiid. In addition, the native hemerobiids were known to be heavily parasitised and there was no doubt that *H. stigma* would suffer similarly (Miller & Clark 1935).

Diomus (=*Scymnus*) *pumilio* (Weise) (Coleoptera: Coccinellidae)

In the early 1930s A.L. Tonnoir, Senior Entomologist, Canberra, had noted that in Australia the native *D. pumilio* was not an uncommon predator on the adelgid on pines, and offered some to Clark at Nelson (FRI files). In early 1936 about 300 adults and larvae were dispatched but only 17 adults, six pupae and two larvae arrived alive. Larval cannibalism and the escape of adults from a container damaged in transit were believed to be the cause. The adults together with emergents from the pupae were placed on twigs infested with *P. laevis*. A further consignment, of adults only, was sent between April and June 1936, and a 'large proportion' was received alive. All were placed on *Pineus* material in the insectary, and a 'fair proportion' survived the winter (FRI files). Clark left when the Forest Biological Research Station at the Cawthron Institute closed, and it is not known what became of the surviving adults or whether any were released.

There is no record of any coccinellid attacking *P. laevis* in New Zealand.

Chrysopa spp. (Neuroptera: Chrysopidae)

There is no mention by New Zealand authors of the two species of *Chrysopa* which Clausen (1978) says were obtained from North America in 1926 but which did not become established. In fact Clark categorically states that the 1932 *Leucopis* sp. introductions were the first attempts at control of *P. laevis*.

Evaluation

Leucopis tapiae is the most important predator of *P. laevis*. The larvae are easily detected amongst adelgids collected from pines anywhere in New Zealand. It has not been found amongst or bred from *Dreyfusia* (=*Adelges*) *nordmannianae* (Eckstein) which infests firs (*Abies* spp.), and is the only other adelgid present in this country.

Conclusions

There is no need for other biological control introductions or any further study unless there is a noticeable increase in the occurrence of *P. laevis*, or another species of adelgid becomes established on pine in New Zealand.

Literature Cited

Cawthron Institute (1935) Annual Report, pp. 13.

Clark, A.F. (1932) Insects infesting *Pinus radiata* in New Zealand. *New Zealand journal of science and technology* 13, 235-243.

Clark, A.F. (1932) Biological control of forest insect pests. Pp. 585-588 in Miller D; Clark A.F.; Dumbleton L.J., Biological Control of noxious insects and weeds in New Zealand. *New Zealand journal of science and technology* 18, 579-593.

Clausen, C.P. (1978) Pine aphid (*Pineus laevis* (Mask.) (*P. boerneri* Annand)). Pp. 49-50 in Clausen C.P. (ed.), Introduced parasites and predators of arthropod pests and weeds: a world review. *U.S. Department of Agriculture, Agriculture Handbook* 480.

Eastop, V.F. (1966) A taxonomic study of Australian Aphidoidea (Homoptera). *Australian journal of zoology* 14, 399-592.

Forest Research Institute, file E86.

McAlpine, J.F. (1971) A revision of the subgenus *Neoleucopis* (Diptera: Chamaemyiidae). *Canadian entomologist* 103, 1851-1874.

Maskell, W.M. (1885) Note on the aphidian insect infesting pine trees, with observations on the name '*Chermes*' or '*Kermes*'. *Transactions and Proceedings of the New Zealand Institute* 17, 13-19.

Miller, D. (1950) Catalogue of the Diptera of the New Zealand sub-region. *DSIR bulletin* 100, 194 pp.

Miller, D; Clark, A.F. (1935) Control of forest insects pests. Distribution of parasites in New Zealand. *New Zealand journal of science and technology* 16, 301-307.

Rawlings, G.B. (1953) Insects of *Pinus radiata* forests in New Zealand. *New Zealand forest research notes* 1(8), 1-19.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical Communication, Commonwealth Institute of Biological Control* 1, 102 pp.

Zondag, R. (1977) *Pineus laevis* (Maskell) (Hemiptera : Aphidoidea : Adelgidae). Pine twig chermes or pine woolly aphid. *Forest and timber insects in New Zealand* 25. New Zealand Forest Service, Wellington. 4 pp.

Sirex noctilio F., sirex wood wasp (Hymenoptera: Siricidae)

M.J. NUTTALL

Pest Status

The progenitors of the first sirex wood wasp, *Sirex noctilio* F., found in the Wairarapa in 1900 (Miller & Clark 1935), would presumably have been accidentally brought into the country as larvae in timber from Europe during the late 19th century. The insect was not considered important until the late 1920s when deaths attributed to it began to occur amongst trees in recently planted but overcrowded plantations of exotic pines (*Pinus*) (Clark 1927). Later there were major losses in the period 1946-51 when up to one third of the trees in 120,000 hectares of radiata pine *Pinus radiata* in the central North Island were killed (Gilmour 1965). These stands, which were unthinned and considerably overstocked, were also under stress from a series of unusually dry summers (Rawlings 1948). In some respects the high mortality caused by the wood wasp was beneficial since it removed trees that would have been thinned out had labour and a market for the thinnings been available (Rawlings & Wilson 1949). Since 1951 there have been scattered outbreaks of the wood wasp in various forests in both main islands, mostly where trees became stressed by such things as overcrowding, lack of water, too severe pruning, or damage to remaining trees caused by logging activities.

During the summer *S. noctilio* oviposits into the wood of living pine trees, and occasionally into moribund larch and spruce. At the same time the insect deposits a mucus and a symbiotic fungus *Amylostereum areolatum* (Fries) Boidin the combined effect of which may cause trees to die (Coutts 1969a, 1969b). Eggs hatch after a minimum of nine days, and larvae tunnel through the wood invaded by the fungus. Pupation occurs inside the tree, and the resulting adults chew their way to the outside. In New Zealand most emerge January-March and the usual life cycle is one year, although some may stay as larvae in the wood for a second year (Rawlings 1948).

Control has been achieved by a combination of good forest management and the presence of natural enemies (Zondag & Nuttall 1977). These latter include several parasitoids, mostly deliberately introduced, which destroy the wood wasp larvae (Nuttall 1980), and a strain of the nematode *Deladenus siricidicola* Bedding (Neotylenchidae) which sterilises the adult female (Bedding 1972). This nematode, discovered in 1962 (Zondag 1962), must have arrived in New Zealand inside its host.

Background

In 1927 David Miller, Government Entomologist, requested parasitoids for the control of *S. noctilio* from the Imperial Institute of Entomology, London, now CIBC. *Rhyssa persuasoria persuasoria* (L.) (Ichneumonidae) arrived in 1928-29 and 1931, releases were made, and establishment achieved. Larvae of *Ibalia leucospoides leucospoides* (Hochenwarth) sent at the same time travelled poorly and failed in rearing. In 1950 and 1951 *I. l. leucospoides* was successfully introduced from the United Kingdom (Rawlings 1951, 1952, 1953). In 1951 the native orussid *Guiglia schauinslandi* (Ashmead) was found to be parasitic on *S. noctilio* larvae (Rawlings 1957), and in 1956 *Rhyssa lineolata* (Kirby), a self-introduced parasitoid from North America, was discovered in New Zealand (Nuttall 1974).

Following the discovery of *Sirex noctilio* on the Australian mainland in December 1961 cooperation between the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the New Zealand Forest Service resulted in several other parasitoids being sent to New Zealand for breeding (Forest Research Insitute (FRI) 1962). Over the next seven years consignments came from stations of the CIBC in California, the Himalayan regions of India and Pakistan, and Japan; the Sirex Biological Control Unit established in the United Kingdom by the Australian Government; and the Tasmanian insectaries of the CSIRO. One of the parasitoids sent, *Megarhyssa nortoni nortoni* (Cresson), became well established and another, *Ibalia leucospoides ensiger* Norton was recovered up to seven years after release.

Table 52.1 Parasitoids received alive 1928-1968

Species	Origin & year	Larvae	Pupae	Adults	
				Male	Female
Ibalia leucospoides ensiger	USA 1963	–	–	19	24
	USA 1966	–	–	110	100
	USA 1967	–	–	188	186
	USA 1968	–	–	99	98
I. leucospoides leucospoides	UK 1931	21	–	–	–
	UK 1950	107+	–	19	18
	UK 1951	20	–	70	95
Megarhyssa emarginatoria	Europe 1965	–	–	3	3
M. nortoni nortoni	USA 1962	–	–	–	2
	USA 1963	–	–	1	2
	USA 1964	–	–	144	233
M. praecellens	Japan 1966	–	–	14	4
'*Rhyssa*' sp. (See text)	USA 1964	–	–	16	8
Rhyssa amoena	Europe 1965	–	–	2	4
	Europe 1967	–	–	24	21
	Europe 1968	–	–	14	17
R. crevieri	Canada 1968	–	–	13	27
R. persuasoria himalayensis	Pakistan 1963	393	36	4	4
	India 1963	–	–	–	30
	India 1964	–	–	60	239
	India 1965	–	–	2	186
R. persuasoria persuasoria	UK 1928-29	814	40		72*
	UK 1931	4569	1166		1*
	UK 1950 (See text)	472	–	–	–
Schlettererius cinctipes	USA 1964	–	–	2	5

+Plus 104 siricid larvae thought to contain *I. leucospoides leucospoides* larvae
*Sex not specified

Importation, Releases and Recoveries

Summaries of parasitoid importations, releases and recoveries are given in Tables 52.1 and 52.2.

Table 52.2 Number of parasitoids liberated

Species	Years	No. of forests	Males	Females	First recovered
Ibalia leucospoides ensiger	1966-71	14	1883	1729	1968
I. leucospoides leucospoides	1954-63, 1965-66, 1968 & 1976-78	63*	8537	8096+	1957
Megarhyssa nortoni nortoni	1964-70, 1972-73, 1975-80, 1982-84	33	1258	1863	1968
Rhyssa persuasoria himalayensis	1964-65, 1967 & 1969-70	5	89	198	–
Rhyssa persuasoria persuasoria	1929-36, 1943-50	c.33*	52**	c.3500	1936

*Logs containing parasitoid larvae also placed in several of these forests
+Plus 50 individuals, sex not specified, released in one forest
**Male numbers for 1929-32 only

Rhyssa persuasoria persuasoria (L.) (Hymenoptera: Ichneumonidae)

Larvae of this parasitoid, collected from forests in Wales and the south of England by H.S. Hanson of Farnham House Laboratory (later CIBC), were sent by sea to the Cawthron Institute, Nelson where Miller was now chief of the Entomological Department and also Director of the newly formed Forest Biological Research Station. The larvae were shipped under cool storage, but some pupated and a number of these developed into adults during the voyage (Miller & Clark 1935).

During the period December 1928 to May 1929, 814 larvae, 40 pupae and 72 adults were received alive. Larvae and pupae were placed in rearing boxes and the first emergences were obtained in January 1929 and continued to May 1929. Further adults were obtained from September 1929 to January 1930 from larvae which had carried over the winter. In March, April and August 1931, 4,569 larvae, 1,166 pupae and one adult were received alive. Apart from pupae and prepupae in the March consignments all were kept in cool storage (5°C) and removed to ordinary temperatures in the spring (October). Almost 15% of the 7,830 individuals dispatched from the U.K. died in transit, two-thirds of the emerging adults were male and many of the females emerged with damaged ovipositors. Only 179 females were liberated (Miller & Clark 1935, 1937).

Some females from the 1931 consignments were used for insectary oviposition on logs infested with *S. noctilio* larvae. By early 1937 four New Zealand generations had been reared and small liberations were possible at Rotorua 'and in other districts' such as Hanmer and Nelson. However the total number of females placed in the field 'did not reach two hundred' (FRI files, Miller & Clark 1937).

The first recoveries from the field were made in the 1936/37 season from two districts in the South Island, Moutere (Nelson) and Hanmer (Miller & Clark 1937).

Annually from 1943 to 1950 the Cawthron Institute brought into their insectaries logs infested with *S. noctilio* from forests where *R. p. persuasoria* was established, and the emerging adults were liberated in 16 South Island and five North Island locations. In 1949 and 1950 some distribution of *R. p. persuasoria*, either as larvae in logs infested with *S. noctilio*, or as adults from insectary emergences was made by the recently created Forest Research Institute (FRI), Rotorua, into the nearby exotic pine plantations at Matahina, Kaingaroa, Rotoehu, and Tokoroa (FRI files). By 1950 establishment was known in the North Island at Riverhead (north of Auckland), Atiamuri (near Tokoroa), Matahina, Rotorua and Taupo; and, in addition to the previous South Island records, at Balmoral, Darfield and Eyrewell (Canterbury), and Dumgree (near Blenheim) (FRI files).

An unexpected consignment of 472 *R. p. persuasoria* larvae was included by Hanson with his initial consignment of *I. l.leucospoides* sent by air to New Zealand in April 1950. No *R. p. persuasoria* had been requested and, since it was already very well established, rearing was not proceeded with and no liberations were made from this importation (FRI files).

In succeeding years no special collections of logs were made by FRI for the purpose of obtaining specimens of *R. p. persuasoria* for release in New Zealand. Any which did emerge from logs collected for rearing other parasitoids were mostly liberated back into nearby forests where establishment was already known. By 1959 *R. p. persuasoria* had spread naturally to most exotic forests (Zondag 1959), and by 1966 was established in all forests (FRI 1966).

Ibalia leucospoides leucospoides (Hochenwarth) (Hymenoptera: Ibaliidae)

During 1931 Hanson sent 382 *I. l. leucospoides* larvae collected at the same time as *R. p. persuasoria* to New Zealand (FRI files, Hanson 1939). Only 21 survived the sea journey. One was reared to adult – a male (Miller & Clark 1935).

Between October and December 1950, 19 male and 18 female adult *I. l. leucospoides* were received alive by FRI from Hanson by then with the Forestry Commission, Farnham, U.K. This was under an arrangement with the Commonwealth Bureau of Biological Control (later CIBC). Oviposition occurred into *S. noctilio* embryos and newly hatched larvae present in moisture reduced *P. radiata* logs which had been exposed to oviposition by *S. noctilio* females in the Rotorua insectaries. The first New Zealand generation of *Ibalia l. leucospoides* emerged in early 1952 (Rawlings 1951, 1952). Also received alive in 1950 were were 107 *I. l. leucospoides* larvae, and 104 siricid larvae thought to be parasitised (Rawlings 1952), but rearing was not successful and it was decided to concentrate on obtaining adult parasitoids only (FRI files).

From August to October 1951, 70 male and 95 female adult *I. l. leucospoides* were received alive from England. Oviposition occurred and progeny emerged January-March 1953 (Rawlings 1953). Twenty larvae were received in November 1951 from which four males were reared (FRI 1952, Zondag 1959). No further imports were made. Insectary rearing continued until 1959 (FRI 1959), and subsequently supplies for liberation were obtained from established populations. Liberations were made in Whakarewarewa (Bay of Plenty) and Eyrewell (North Canterbury) forests in 1954 (Zondag 1959), and thereafter in forests and plantations throughout the country annually until 1963, and then in the years 1965, 1966, 1968 and 1976-78 (FRI files). In addition logs containing *I. l. leucospoides* were placed in seven forests in the Southland, Central Otago and Dunedin areas in 1963-1965 (FRI files). The first field recovery was from Rotoehu (Bay of Plenty) in 1957 two years after liberation (Zondag 1959). By 1983 it had been recorded from 97 forests and plantations (FRI files), and is certainly present throughout the country wherever *S. noctilio* occurs.

Megarhyssa nortoni nortoni (Cresson) (Hymenoptera: Ichneumonidae)

In 1962, two adult female *M. n. nortoni* were received alive from the Californian Station of the CIBC. In 1963, one male and two females arrived and in 1964, 144 males and 233 females were sent (FRI files). Oviposition occurred onto *S. noctilio* larvae in pine logs in the FRI insectary and the first progeny emerged in 1963. Owing to a shortage of suitable logs in the insectary, the last two consignments received in 1964 were released at Waitangi (Northland) where winter temperatures would be suitable for oviposition (FRI 1964). The first liberation of insectary reared specimens was at Tairua in 1964 (FRI files). Insectary culturing continued for the next six years (FRI 1970), and after that specimens for release were obtained from logs collected from forests where establishment had already occurred (FRI files). By 1988 *M. n. nortoni* had been recovered from 17 of the 33 forests and plantations in which it had been released, and was known to have spread naturally to 23 other localities (FRI files).

Rhyssa persuasoria himalayensis Wilkinson (Hymenoptera: Ichneumonidae)

In 1963, four male and four female adults, 32 male and four female pupae, and 393 larvae of *R. p. himalayensis* were received alive by FRI from the Pakistan station of the CIBC (FRI files). A total of 139 adults was reared (91 males and 48 females of which 16 had deformed ovipositors). Also in 1963, 30 adult females were received alive from the CIBC Srinagar substation, India (FRI files). These together with the specimens from Pakistan were used for insectary oviposition and the first progeny emerged in March 1964. In 1964, 60 male and 239 female adults arrived alive from India. Most of the females, apart from 44 which were liberated at Waipoua (Northland) in August 1964, were released in the insectary (FRI 1964, FRI files). In 1965, two males and 186 females were received alive from India (FRI 1965) and used for insectary oviposition. Insectary culturing ceased in 1970 by which time releases of reared specimens had been made at Russell (Northland), Ashley (North Canterbury), Herbert (south of Oamaru), and Naseby (Central Otago). *Rhyssa p. himalayensis* has never been recovered from the field.

Ibalia leucospoides ensiger Norton (Hymenoptera: Ibaliidae)

The genus *Ibalia* was revised by Kerrich (1973) who placed the North American *I. ensiger* as a subspecies of *I. leucospoides*. In 1963, 19 male and 24 female adult *I. l. ensiger* were received from the CIBC station in California (FRI 1963). Many were carrying mites which were removed using a fine brush dipped in 5% alcohol. The insects were sluggish and oviposition in the insectary was not seen. No progeny were obtained (FRI files).

In 1966, 1967 and 1968 *I. l. ensiger* were sent from the Tasmanian insectaries of the CSIRO (Taylor 1976). These were from cultures from consignments sent there from USA in 1963. Some of the females (33) after being used for oviposition in the FRI insectary in 1966 were liberated at Berwick (Southland). Of the 188 males and 186 females received in 1967, 50 of each sex were retained for insectary culture and the rest, together with insectary emergents, were liberated in Kaingaroa (Bay of Plenty), Omihi (North Canterbury), and Tahorakuri (near Taupo). Of the 99 males and 98 females received alive in 1968, 24 males and 23 females were retained for insectary culture whilst the balance was released in Otago Coast (south of Dunedin) and, supplemented with reared specimens, at Ashley (North Canterbury). Liberation of reared specimens continued in 1969 and 1970. Culturing ceased in 1970 (FRI 1970) and the last emerging specimens were released at Motueka (Nelson) the following year (FRI files). Recoveries have been made from six of the 14 forests in which liberation has been made, but because of interbreeding with *I. l. leucospoides* it has not been recognised in collections since 1976 (FRI files).

Schlettererius cinctipes (Cresson) (Hymenoptera: Stephanidae)

In 1964, two males and five females of this North American species, shown by culturing in the Tasmanian insectaries of the CSIRO to be a primary parasitoid of siricids (Taylor 1967a), were sent to FRI from California. No insectary oviposition was seen and no progeny were obtained (FRI files).

'*Rhyssa*' spp. (Hymenoptera: Ichneumonidae)

In 1964 two consignments of '*Rhyssa*' spp., a total of 16 males and eight females, were received alive from California. These were later identified as a mixture of male *R. persuasoria persuasoria*, male and female *R. alaskensis* Ashmead, and, most numerous, male and female *Pseudorhyssa maculicoxis* (Kriechbaumer). This latter genus is cleptoparasitic on siricids by first destroying the rhyssine larva already present on the host (Spradbery 1969), and would not have been a welcome introduction. No oviposition was seen in the insectary and no progeny emerged (FRI files).

Megarhyssa emarginatoria (Thunberg) (Hymenoptera: Ichneumonidae)

In 1965, three males and three females, collected in Europe were sent to FRI from Silwood Park, U.K. (FRI 1965). Oviposition was seen only once in the insectary and no progeny were obtained (FRI files).

Rhyssa amoena Gravenhorst (Hymenoptera: Ichneumonidae)

A consignment of two male and four female *Rhyssa amoena* from Europe was sent from Silwood Park, U.K., to FRI in 1965 (FRI 1965). Only a single male resulted from insectary oviposition. In 1967, 24 males and 21 females arrived alive and in 1968, 14 males and 17 females (FRI 1967, 1968). Only a few progeny were obtained from insectary rearing which continued to 1971, and no liberations were made (FRI files).

Megarhyssa praecellens (Tosquinet) (Hymenoptera: Ichneumonidae)

In 1966, 14 male and four female adult *M. praecellens* were received from Japan (FRI 1966). Only one male and two females were obtained from insectary oviposition, and the following generation consisted of one male only. No liberations were made (FRI files).

Rhyssa crevieri (Provancher) (Hymenoptera: Ichneumonidae)

Thirteen male and 27 female *R. crevieri* were received alive from the CSIRO insectaries Tasmania in 1968 (FRI 1968). These were first generation emergences from an import from Canada (Taylor 1976). Only a few progeny emerged from FRI insectary oviposition and no liberations were made (FRI files).

Evaluation

Ibalia leucospoides leucospoides became established readily, spread rapidly, and is present wherever *S. noctilio*-killed trees are found. Usually not less than 30 females were liberated at one time, but even very small numbers resulted in successful establishment. The best example was at Eyrewell (North Canterbury) where in 1959 the parasitoid was well established 6 km from the spot where nine females had been released in 1955. In other instances the parasitoid appeared 125 km and 84 km distant from places where it had been liberated nine years earlier (FRI files).

Megarhyssa nortoni nortoni has become equally well established, and the first indication of its rapid natural spread was its appearance 65 km distant from its nearest point of liberation

nine years earlier (FRI files). Later at another locality it was found established 115 km from the nearest release made only five years previously, however it could have also originated from a liberation made 11 years earlier than this 150 km away. *Rhyssa p. persuasoria* did not at first spread so rapidly. Only 11 records of establishment had been made by 1950 (FRI files) and Rawlings (1948) stated that it was common in Whakarewarewa forest (Bay of Plenty) but did not appear to have crossed the few kilometres separating it from Waiotapu forest even though there were numerous pine trees scattered over the area between. However, eleven years later this parasitoid was reported as being well established in most exotic pine forests (Zondag 1959). By 1966 it was present in all forests (FRI 1966).

Parasitism of *S. noctilio* by *I. l. leucospoides* is usually between 25–35% but can be as high as 55% (FRI files), and the combined effect of this parasitoid and the rhyssines may kill over 70% of *S. noctilio* larvae in a particular forest area (Nuttall 1980).

Ibalia leucospoides ensiger is known to interbreed with the well established *I. leucospoides leucospoides* and separate populations cannot be recognised. *Rhyssa p. himalayensis* will have probably similarly interbred with the established *R. p. persuasoria*, and its recognisable marking becomes lost in the progeny.

Schlettererius cinctipes oviposits satisfactorily on *Sirex noctilio* in radiata pine (Taylor 1967b), but the reason for its failure to do so at FRI is not known. Failure in rearing *M. emarginatoria*, *M. praecellens*, *R. amoena* and *R. crevieri* may have been because the natural siricid hosts of these rhyssines are present in genera other than *Pinus* (Taylor 1976). The existence of such ecological preferences by the different siricid species, and some of their parasitoids has been shown by Spradbery & Kirk (1978).

Conclusions

The introduction of certain parasitoids into New Zealand has been a success. Their presence, together with the parasitic nematode, and good forest management has been effective in keeping losses caused by *S. noctilio* at a low level.

Literature Cited

Bedding, R.A. (1972) Biology of *Deladenus siricidicola* (Neotylenchidae) an entomophagous-mycetophagous nematode parasitic in siricid woodwasps. *Nematologica* 18, 482-493.

Clark, A.F. (1927) The infestation of *Sirex juvencus* in Canterbury. *Te Kura Ngahere* 2, 10-16.

Coutts, M.P. (1969a) The mechanism of pathogenicity of *Sirex noctilio* on *Pinus radiata*. I. Effects of the symbiotic fungus *Amylostereum* sp. (Telophoraceae). *Australian journal of biological science* 22, 915-924.

Coutts, M.P. (1969b) The mechanism of pathogenicity of *Sirex noctilio* on *Pinus radiata*. II. Effects of *S. noctilio* mucus. *Australian journal of biological science* 22, 1153-1161.

Forest Research Institute, file E86.

Forest Research Institute (1952) Annual report, 17.

Forest Research Institute (1959) Annual report, 29, 100.

Forest Research Institute (1962) Annual report, 42-43.

Forest Research Institute (1963) Annual report, 46-47.

Forest Research Institute (1964) Annual report, 55, 57.

Forest Research Institute (1965) Annual report, 59.

Forest Research Institute (1966) Annual report, 62-63.

Forest Research Institute (1967) Annual report, 58-59.

Forest Research Institute (1968) Annual report, 61-63.

Forest Research Institute (1970) Annual report, 55.

Gilmour, J.W. (1965) The life cycle of the fungal symbiont of *Sirex noctilio*. *New Zealand journal of forestry* 10, 80-89.

Hanson, H.S. (1939) Ecological notes on the *Sirex* wood wasps and their parasites. *Bulletin of entomological research* 30, 27-65.

Kerrich, G.J. (1973) On the taxonomy of some forms of *Ibalia* Latreille (Hymenoptera: Cynipoidea) associated with conifers. *Zoological journal of the Linnean Society* 53, 65-79.

Miller, D; Clark, A.F. (1935) *Sirex noctilio* (Hym.) and its parasite in New Zealand. *Bulletin of entomological research* 26, 149-154.
Miller, D; Clark, A.F. (1937) The establishment of *Rhyssa persuasoria* in New Zealand. *New Zealand journal of science and technology* 19, 63-64.
Nuttall, M.J. (1974) *Rhyssa lineolata* (Hymenoptera: Ichneumonidae), as a parasite of *Sirex noctilio* in New Zealand. *New Zealand journal of forestry science* 4, 487-494.
Nuttall, M.J. (1980) Insect parasites of sirex (Hymenoptera: Ichneumonidae, Ibaliidae and Orussidae). *Forest and timber insects in New Zealand* 47. New Zealand Forest Service, Wellington. 12 pp.
Rawlings, G.B. (1948) Recent observations on the *Sirex noctilio* population in *Pinus radiata* forests in New Zealand. *New Zealand journal of forestry* 5, 411-421.
Rawlings, G.B. (1951) The establishment of *Ibalia leucospoides* in New Zealand. *New Zealand forest research notes* 1(3), 1-14.
Rawlings, G.B. (1952) Progress in establishment of *Ibalia leucospoides* a parasite of *Sirex noctilio*, the horntail borer of pine. *New Zealand science review* 10, 107-108.
Rawlings, G.B. (1953) Rearing of *Sirex noctilio* and its parasite *Ibalia leucospoides*. *New Zealand forest research notes* 1(8), 20-34.
Rawlings, G.B. (1957) *Guiglia schauinslandi* (Ashmead) (Hym. Orussidae) a parasite of *Sirex noctilio* (Fabricius) in New Zealand. *The entomologist* 90(1125), 35-36.
Rawlings, G.B.; Wilson, N.M. (1949) *Sirex noctilio* as a beneficial and destructive insect to *Pinus radiata* in New Zealand. *New Zealand journal of forestry* 6, 20-29.
Spradbery, J.P. (1969) The biology of *Pseudorhyssa sternata* Merrill (Hym., Ichneumonidae), a cleptoparasite of siricid woodwasps. *Bulletin of entomological research* 59, 291-297.
Spradbery, J.P.; Kirk A.A. (1978) Aspects of the ecology of siricid woodwasps (Hymenoptera: Siricidae) in Europe, North Africa and Turkey with special reference to the biological control of *Sirex noctilio* F. in Australia. *Bulletin of entomological research* 68, 341-359.
Taylor, K.L. (1967a) The introduction, culture, liberation, and recovery of the parasites of *Sirex noctilio* in Tasmania, 1962-67. *Division of Entomology technical paper* 8. Commonwealth Scientific and Industrial Research Organisation, Australia. 19 pp.
Taylor, K.L. (1967b) Parasitism of *Sirex noctilio* F. by *Schlettererius cinctipes* (Cresson) (Hymenoptera: Stephanidae). *Journal of the Australian Entomological Society* 6, 13-19.
Taylor, K.L. (1976) The introduction and establishment of insect parasitoids to control *Sirex noctilio* in Australia. *Entomophaga* 20, 429-440.
Zondag, R. (1959) Progress report on the establishment in New Zealand of *Ibalia leucospoides* Hochenw., a parasite of *Sirex noctilio* (F.). *New Zealand forest research notes* 20, 1-10.
Zondag, R. (1962) A nematode disease of *Sirex noctilio* (F.). Interim research release, New Zealand Forest Service, Wellington. 6 pp.
Zondag, R; Nuttall, M.J. (1977) *Sirex noctilio* Fabricius (Hymenoptera: Siricidae). Sirex. *Forest and timber insects in New Zealand* 20. New Zealand Forest Service, Wellington. 8 pp.

Tuberculatus annulatus (Hartig), oak aphid (Homoptera: Callaphididae)

G.P. WALKER

Pest Status

The oak aphid *Tuberculatus annulatus* (Hartig), previously known as *Myzocallis annulatus* (Hartig) (Cottier 1953), is common on introduced oaks (*Quercus* spp.) and chestnuts (*Castanea* spp.) throughout most of New Zealand. The aphids are found during the summer months feeding on the underside of leaves, where they produce copious amounts of honeydew. This supports sooty moulds which lower the aesthetic appearance of these mainly ornamental trees. There may also be some defoliation but damage is not usually serious (Cottier 1953).

There are yellow and green forms of the oak aphid, and in autumn oviparous females can be found in abundance along with the black, glistening, overwintering eggs which are usually found around the buds. Rohitha & Penman (1984) note that the yellow form develops faster and is more abundant in the field than the green form. Oak aphid occurs naturally in Europe, Asia and North Africa. It is very common in Scandinavia, Britain, Germany and western U.S.S.R and has been introduced into Australia, New Zealand and North and South America (Heie 1982).

Background

There are few records of native parasitoids attacking oak aphid in New Zealand. Valentine (1967) lists two parasitoids, a *Trioxys* sp. (Braconidae) and the pteromalid *Pachyneuron siphonophorae* (Ashmead). In Tasmania the insect predators of oak aphid include ladybird beetles, lacewing larvae and occasionally the larvae of hover flies (Evans 1943). Although there are no records of predation in New Zealand a similar complex of aphid predators probably attack oak aphid in New Zealand.

In Australia a biological control programme was initiated against oak aphid in 1936. The Council for Scientific and Industrial Research (CSIR) carried out investigations in England and *Aphelinus subflavescens* (Westwood) (then known as *Aphelinus flavus* (Nees)) was introduced (Wilson 1960). Bouček & Graham (1978) use the subgeneric name *Mesidiopsis* for this species. This programme apparently created interest in New Zealand, although at this time E.S. Gourlay advised that the same parasitoid was already common on oak aphid in Nelson (DSIR files), having probably been introduced accidentally with young oak trees imported from abroad.

Importations, Releases and Recoveries

Aphelinus subflavescens (Westwood) (Hymenoptera: Aphelinidae)

All importations of parasitoids into New Zealand appear to have originated from the Australian programme. Shipments were sent to Nelson and D. Miller acknowledges their arrival in March 1939 (DSIR files). E.S. Gourlay (DSIR files) and Valentine (1963) recognised that *A. subflavescens* was already present in New Zealand at the time of introduction. Doubt as to the origin of the imported strain of *A. subflavescens* appears to originate from E.W. Valentine's DSIR file records which indicate Europe as the source. Presumably Valentine

was referring to the original source which is also cited by Cameron *et al.* (1987). *A. subflavescens* has been reared out of oak aphid from Christchurch, Nelson and Auckland (DSIR files).

Evaluation and Conclusions

It is uncertain if the imported *A. subflavescens* established in New Zealand. As there are no reported field studies of oak aphid and few records of *A. subflavescens* the importance of the parasitoid is unclear. E.S. Gourlay reported that before the introduction *A. subflavescens* became extremely abundant each year towards autumn (DSIR files). Oak aphid is presently not considered to be a problem in New Zealand except on occasional ornamental trees (J. Bain pers. comm.) so no further biological control programmes appear necessary.

Literature Cited

Bouček, Z.; Graham, M.W.R. (1978) British check-list of Chalcidoidea (Hymenoptera): taxonomic notes and additions. *Entomologist's gazette* 29, 225-235.

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242, 51 pp.

Cottier, W. (1953) Aphids of New Zealand. *DSIR bulletin* 106, 382 pp.

DSIR, Entomology Division file BC 1/4.

Evans, J.W. (1943) Insect pests and their control. Government Printer, Tasmania. 178 pp.

Heie, O.E. (1982) The Aphidoidea (Hemiptera) of Fennoscandia and Denmark. II. The family Drepanosiphidae. *Fauna entomologica Scandinavica* 11, 55-56.

Rohitha, B.H.; Penman, D.R. (1984) Growth and development of the oak aphid, *Tuberculoides annulatus* (Homoptera: Aphididae) on excised leaf discs. *New Zealand entomologist* 8, 83-86.

Valentine, E.W. (1963) New records of hymenopterous parasites of Homoptera in New Zealand. *New Zealand journal of science* 6, 6-13.

Valentine, E.W. (1967) A list of the hosts of entomophagous insects of New Zealand. *New Zealand journal of science* 10, 1100-1210.

Wilson, F. (1960) A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Technical communication, Commonwealth Institute of Biological Control* 1, 102 pp.

PART 5.

Weeds

Biological control of weeds research in New Zealand has a long history. A review of early biological control work by Miller (1970) recorded that such research began in 1927, although early correspondence shows that the first importations of insects were made even earlier than this, in 1925 (DSIR files). Miller's review contains an immense amount of detail concerning insect species which were imported and released in New Zealand between 1927 and 1948 for the biological control of weeds. The following chapters extend Miller's review by including information about insect species which were imported into New Zealand during the early years but which were never released. More recent programmes are reviewed to the end of 1987.

Apart from the programmes aimed at the control of waterweeds and algal blooms, all of the biological control programmes described in this section have been carried out either by the Cawthron Institute or its successor, Entomology Division, DSIR. A total of 40 species have been imported and 22 of these have been released against 11 weeds. Three species have been released only recently and so it is too early to determine their fate, but 11 other species are known to have become established. No diseases have been imported for weed control.

Biological control of weeds research was led initially by R.J. Tillyard of the Cawthron Institute, Nelson. Under his guidance, research began into the control of four weeds considered to be of serious concern to New Zealand agriculture. Insect species were imported which attacked blackberry (*Rubus fruticosus* L. agg.) (Chapter 64), ragwort (*Senecio jacobaea* L.) (Chapter 65), gorse (*Ulex europaeus* L.) (Chapter 66) and foxglove (*Digitalis purpurea* L.) (Chapter 62). Tillyard left the Institute in 1927 and in the following year D. Miller took over the leadership of the research. In that year the programme against piripiri (*Acaena anserinifolia* (Forster & G. Forster) J. Armstrong) (Chapter 54) began. A total of 17 insect species was imported for these weeds between 1925 and 1931, and releases of five insects to attack ragwort, gorse and piripiri continued into the 1940s. Three of these became established. Other early workers associated with this work included E.S. Gourlay and J.M. Kelsey.

Between 1931 and 1965, only four insect species were imported and released for weed control, three against St John's wort (*Hypericum perforatum* L.) (Chapter 63) and one against Mexican devil weed (*Ageratina adenophora* (Sprengel) R. King & H. Robinson) (Chapter 55). All four species established. B.B. Given and J.M. Hoy of Entomology Division, DSIR, were responsible for these two programmes respectively.

From 1966 to 1971, V.J. Chapman of the Botany Department, University of Auckland, and staff of the Ministry of Agriculture and Fisheries imported species which attacked aquatic macrophytes (Chapter 58) and algal blooms (Chapter 56). The fish species which have been released against these targets are not expected to be self-sustaining in the New Zealand environment and will be closely managed to achieve weed control. All of the other chapters in this section describe inoculative releases of foreign control agents into the New Zealand environment with the aim of establishing self-sustaining control over the target weed.

The last 15 years have seen renewed interest in the biological control of terrestrial weeds. In 1974, *Rhinocyllus conicus* (Froelich) was introduced by R.J.B. Power and C.T. Jessep of Entomology Division, DSIR, against nodding thistle (*Carduus nutans* L.). This weevil is now very common and markedly reduces the annual seed crop (Chapter 59). Other species were imported for control of Californian thistle (*Cirsium arvense* (L.) Scopoli) by C.T.

Jessep and L.E. MacCarter of Entomology Division, DSIR (Chapter 60). Both programmes are continuing.

During the period from 1931 to 1980 there were never more than three staff (often only one) working in this field. However, since 1980 there has been a considerable increase in efforts to control weeds biologically and presently there are eight staff working on six programmes. Two of these, against gorse and ragwort, have resumed after a long period of inactivity. Programmes against alligator weed (*Alternanthera philoxeroides* (C. Martius) Grisebach) (Chapter 57) and broom (*Cytisus scoparius* (L.) Link) (Chapter 61) have begun only recently.

In addition to those reviewed in this section, programmes against variegated thistle (*Silybum marianum* (L.) Gaertner (Asteraceae)) and sweet briar (*Rosa rubiginosa* L. (Rosaceae)) have been initiated in the past but no natural enemies have ever been imported (DSIR files, Herting 1964). The severe damage caused to manuka, *Leptospermum scoparium* Forster & Forster f. (Myrtaceae), by *Eriococcus orariensis* Hoy (Hemiptera: Eriococcidae) has been widely quoted as an example of biological control of a native weed (DeBach 1974, Julien 1987). This cannot strictly be considered as a biological control programme because the insect was accidentally rather than deliberately introduced (Syrett *et al.* 1985). *E. orariensis* was first discovered attacking manuka in 1937. A survey carried out in 1948 revealed that it was widespread in Canterbury and was slowly killing stands of mature bushes (Hoy 1953). Hoy noted that although manuka was a recurrent problem for many farmers, it played a very important role in the regeneration of native forests and in the control of erosion (Hoy 1949). For this reason, no official attempt was made to spread *E. orariensis*. However, farmers interested in long-term control of manuka transferred the species from infested areas until it was widely distributed through both the North and South Islands. Heavy damage of manuka ensued, which changed the composition of many manuka stands and also allowed the permanent establishment of pasture in many areas (Hoy 1949, 1967). *E. orariensis* remains a common insect and commonly damages manuka plants. The history of manuka control is well documented (Given 1967, Hoy 1949, 1953, Syrett *et al.* 1985).

The programme to control St John's wort, *Hypericum perforatum*, has been the most successful carried out in New Zealand so far. Farmers regarded this weed as a very serious problem in the 1940s when the programme began, but its status as a weed has declined markedly since then (Bascand & Jowett 1982). Miller (1970) gives a graphic account of the damage caused by outbreaks of the introduced chrysomelid *Chrysolina hyperici* (Forster) and describes the control achieved in several heavily infested areas. More recently, Syrett & Hancox (1985) have shown that even low beetle densities can significantly affect the performance of the weed. This programme is discussed in more detail in Chapter 62.

Research into the biological control of weeds has increased dramatically since 1980, and this level of activity is likely to continue for the foreseeable future. Programmes against eight of the 13 target weeds considered in this section are continuing and so these chapters represent an interim report. Although evaluations are under way, it is too early yet to predict the success or otherwise of these projects.

Literature Cited

Bascand, L.D.; Jowett, G.H. (1982) Scrubweed cover of South Island agricultural and pastoral land. 2. Plant distribution and managerial problem status. *New Zealand journal of experimental agriculture* 10, 445-492.

DeBach, P. (1974) Biological control by natural enemies. Cambridge University Press, London, U.K. 323 pp.

DSIR, Entomology Division, file BC 1/4.

Given, B.B. (1967) Biological control of weed and insect pests in New Zealand. *Mushi* 39 (suppl.), 17-22.

Herting, B. (1964) Lepidoptera, Hymenoptera and Diptera attacking *Rosa* in Europe. Unpublished report, Commonwealth Institute of Biological Control. 18 pp.

Hoy, J.M. (1949) Control of manuka by blight. *New Zealand journal of agriculture* 79, 321-324.

Hoy, J.M. (1953) Manuka blight, causative agent. *Sixth New Zealand Weed Conference*, 38-41.

Julien, M.H. (1987) Biological control of weeds, a world catalogue of agents and their target weeds. CAB International, Wallingford, U.K. 149 pp.

Miller, D. (1970) Biological control of weeds in New Zealand 1927-1948. *New Zealand Department of Scientific and Industrial Research information series* 74, 104 pp.

Syrett, P.S.; Hancox, N.G. (1985) Effect of an introduced beetle on St John's wort. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 154-157.

Syrett, P.S.; Hill, R.L.; Jessep, C.T. (1985) Conflict of interest in the biological control of weeds in New Zealand. Pp. 391-397 in E.S. Delfosse (ed.) Proceedings of the 6th International Symposium on the Biological Control of Weeds. Agriculture Canada, Ottawa.

Acaena anserinifolia (Forster & G. Forster) J. Armstrong, piripiri (Rosaceae)

R.L. HILL

Pest Status

Piripiri, or hutiwai, is the name collectively applied in New Zealand to species of the genus *Acaena*. Most piripiri species have characteristic globular heads of many-barbed burs which catch in the wool of sheep, matting the fleece. This can reduce the net value of the wool (Henderson 1968, Miller 1970). There are 15 species of *Acaena* in New Zealand, two of which are originally from Australia (B. Macmillan pers. comm.). These occupy a variety of habitats such as stream banks, but it is the species which inhabit grasslands that cause economic damage to wool.

A. caesiiglauca (Bitter) Bergmans and *A. profundeincisa* (Bitter) B. Macmillan grow in high altitude native grasslands where fine-woolled sheep graze. Such wool is particularly affected by *Acaena* burs (Henderson 1968). The Australian species *A. novae-zelandiae* Kirk and *A. agnipila* Gandoger can be common in lower altitude sheep pastures (B. Macmillan pers. comm). *A. novae-zelandiae* is now regarded as a minor weed of reserves in north-east England (Gynn & Richards 1985).

The commonest species in New Zealand, and hence the most damaging, is *A. anserinifolia* (Forster & G. Forster) J. Armstrong. This species was originally restricted to bush margins and forest clearings, but when forests were felled and developed as pasture during the 19th century, piripiri spread rapidly, often carried by sheep and dogs (Thomson 1922). By 1928 it was a serious and intractable problem for farmers on extensively grazed pastures in both the North and the South Islands.

Background

Several insects have been recorded attacking piripiri in New Zealand, but with one exception, these are not known to cause significant damage (Miller 1970, Spiller & Wise 1982). In the late 1920s there were numerous reports that large areas of piripiri were dying (DSIR files). Dead plants usually carried heavy infestations of the polyphagous mealybug *Chryseococcus arecae* (Maskell), previously known as *Dactylopius arecae* Maskell (Cox 1987), which may have contributed to control of the weed in such areas.

There are probably more species of *Acaena* in South America than in any other region (B. Macmillan pers. comm.) so biological control agents were sought there. The insect fauna of *Acaena* spp. was studied by Brother Claude Joseph of the Instituto San José in Temuco, Chile, who chose two species, *Altica virescens* Blanchard (Coleoptera: Chrysomelidae) and the sawfly *Ucona acaenae* Smith (Hymenoptera: Tenthredinidae) as the most suitable for establishment in New Zealand. The most promising of these was the yellow and black univoltine tenthredinid sawfly which is 6-8 mm long. Brother Joseph found that adults emerged from May and the females began to lay eggs into piripiri leaves. Each female laid up to 300 eggs over a 2-3 week period. *U. acaenae* reproduced both sexually and asexually but it is not known whether unmated females produce male progeny as well as females. Eggs were visible as swellings in the piripiri leaf. They hatched from mid-May to September and the larvae fed on leaves as well as developing buds and flowers. These larvae were green and grew to 2 cm long before descending to the ground, digging 5-10 cm into the soil and constructing a calcareous cocoon in which they aestivated as prepupae. Most sawflies emerged in the following winter but some had a biennial life history (Miller 1970).

Importations, Releases and Recoveries

A shipment of *A. virescens* eggs was received from Chile, probably in 1930, but the larvae which hatched did not survive. Tests in Chile subsequently showed that this species fed on plants other than *Acaena* spp. and so no further shipments were made (Miller 1970).

Between 1928 and 1940, one shipment of eggs and larvae and 16 shipments of *U. acaenae* prepupae were received from Chile under the name *Antholcus varinervis* (Spinola). A total of 26,407 insects was sent, from which 11,692 sawflies emerged, 94.6% of which were females. An unidentified fungus destroyed many of the prepupae shipped and 184 parasitoids were isolated in quarantine (Miller 1970). Experiments in New Zealand showed that the sawfly did not lay eggs in the foliage of blackberry, raspberry, rose, strawberry or the native species *Rubus australis* Forster f. (Rosaceae). Larvae fed on strawberry leaves but could not complete development on this host. Foliage of the other test species was not attacked.

The first releases were made in June 1936 when 440 sawflies were liberated near Wanganui and a further 5,600 were released near Hunterville, Wanganui and Eltham. Releases were made in June and July of each succeeding year until 1948. The release sites are listed by Miller (1970) and include areas in Nelson, Marlborough and Otago. A total of 30,000 insects was liberated from imported and reared material (Miller 1970).

By 1938, it was reported that *U. acaenae* was increasing in numbers (DSIR files) and although population build-up was slow, observations on two North Island populations suggested that the insect was well established (Miller 1970). One report, however, suggested that the larvae observed were progeny of sawflies released in the same season rather than an established population (DSIR files). These populations were not monitored after 1940 and *U. acaenae* has not been recorded since. More detailed observations were made at a release site near Nelson for a further two years during which time the sawfly caused conspicuous damage to the weed. Unfortunately, the site was destroyed in 1942 and the insect was never recorded again. The Cawthron Institute rearing colony of *U. acaenae* was maintained for many years but finally died out in 1956 (Miller 1970). Further details of importations, releases and recoveries can be found in Miller (1970).

Evaluation

It is still possible that *U. acaenae* populations survive in New Zealand, but since it has not been recorded in the field since 1942, this seems very unlikely. The reasons why the sawfly did not establish successfully are uncertain. Some claim that birds preyed heavily on sawfly larvae but this is unsubstantiated (DSIR files). A fungus was recorded amongst prepupae shipped from Chile (Miller 1970) and this, or another fungus, was common in the rearing colony (DSIR files). Fungal disease may have caused the decline in field populations of the sawfly but this is speculation.

Conclusions

Although *Acaena* spp. were serious weeds in newly-developed pastures throughout the hill-country of New Zealand, by 1929 they appeared to be declining in abundance. There were reports that large areas of piripiri were dying without apparent reason. Some attributed this to natural control by the polyphagous mealybug *Chryseococcus arecae*, which commonly infested the roots of affected plants (DSIR files). One report simply suggested that the soil was 'hutiwai-sick' or no longer able to support the weed (DSIR files). It is now known that *Acaena* spp. prefer low fertility soils and cannot compete in a strong pasture sward (Taylor 1981). As the fertility of New Zealand pastures has improved, so the abundance of piripiri and its importance as a pasture weed has declined.

Wool-scouring techniques have now improved so that moderate amounts of contamination can be removed from the fleece during processing, further reducing the economic importance of piripiri (Henderson 1968). *Acaena* spp. are still commonly found in many parts of New Zealand and burs still catch in the wool of sheep, but this is no longer regarded as a serious problem by sheep farmers.

Acknowledgements

My thanks to Bryony Macmillan for valuable discussions about *Acaena* spp. in New Zealand.

Literature Cited

Cox, J.M. (1987) Pseudococcidae (Insecta: Hemiptera). *Fauna of New Zealand* 11, 230 pp.

DSIR, Entomology Division, file BC 1/4.

Gynn, E.G.; Richards, A.J. (1985) Biological flora of the British Isles. 161 *Acaena novae-zelandiae* T. Kirk. *Journal of ecology* 73, 1055-1063.

Henderson, A.E. (1968) Growing better wool. A.H. & A.W. Reed, Wellington, New Zealand. 108 pp.

Miller, D. (1970) Biological control of weeds in New Zealand 1927-48. *New Zealand Department of Scientific and Industrial Research information series* 74, 103 pp.

Spiller, D.M.; Wise, K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR bulletin* 231, 260 pp.

Taylor, R.L. (1981) Weeds of lawns, pasture and lucerne in New Zealand. R.L. Taylor, Nelson, New Zealand. 136 pp.

Thomson, G.M. (1922) Naturalisation of animals and plants in New Zealand. Cambridge University Press, London, U.K. 607 pp.

Ageratina adenophora (Sprengel) R. King & H. Robinson, Mexican devil weed (Asteraceae)

R.L. HILL

Pest Status

Ageratina adenophora (Sprengel) R. King & H. Robinson is an erect, branching perennial which can grow up to 2 m tall. It has dark stems and broad, heavily-veined, sharp-pointed, dark green leaves approximately 7 cm long. In early summer each plant bears profuse clusters of small white flowers. The closely related species *A. riparia* (Regel) R. King & H. Robinson, which also occurs in New Zealand, has similar flowers but has narrow, pointed leaves (Taylor 1981).

A. adenophora is a native of Mexico but it has been cultivated in many places as an ornamental shrub. It has become a weed in a number of countries including New Zealand, where it is very abundant in Northland and on the Coromandel Peninsula. It grows profusely in under-managed areas such as sparse scrub, forest margins or disused gullies, and heavy infestations can hinder access to water by stock. It can be troublesome on marginal land but is adequately controlled by grazing (Hoy 1960). Opinions on the economic importance of the plant have varied in the past 30 years (Hoy 1960) but it has never been a very important weed in New Zealand.

Background

The first attempt to control *A. adenophora* biologically was made in Hawaii. The plant was brought to the island of Maui as an ornamental shrub around 1860 but spread rapidly to invade thousands of hectares of valuable rangeland. Until 1948 control was achieved by mechanical removal of the plants. In 1945, the stem gall fly, *Procecidochares utilis* Stone (Diptera: Tephritidae) was imported from Mexico. *P. utilis* is a small marble-winged fly which lays its eggs at the growing point of a shoot. Hatching larvae tunnel into the stem and after two weeks a gall becomes visible. Simple galls contain a mean of three larvae each. When the fly is abundant, compound galls containing many larvae form, which can stunt and even kill the plant. Mature larvae tunnel to the surface of the gall leaving only an epidermal window, they then pupate, and emerging flies break out through the window (Bess & Haramoto 1958).

The gall fly established rapidly on Maui and was so damaging that within three years ranchers had ceased control measures, assuming that the fly would soon achieve control of the weed (Bess & Haramoto 1958). Attack by *P. utilis* has since cleared *A. adenophora* from many thousands of hectares of rangeland and it has been completely eliminated from most of the low rainfall areas of Maui except gullies and shaded areas where soil moisture is retained. Surviving plants are stunted and deformed by stem galls which can often coalesce, occupying the whole stem. Little control has been achieved in high rainfall areas but these are of little agricultural importance (Bess & Haramoto 1972).

Successful control of *A. adenophora* has been achieved in Hawaii despite heavy attack on the gall fly by parasitoids which were resident in Hawaii before the fly was introduced. Two of these were introduced from overseas to attack fruit fly pests which are closely related to *P. utilis* (Bess & Haramoto 1972).

A similar programme was carried out in Queensland. *A. adenophora* was first recorded in Queensland only in 1930, but between 1940 and 1950 it spread rapidly to occupy many thousands of hectares of agricultural land. Following the successful control of the weed in Hawaii, Dodd (1961) imported *P. utilis* into Queensland in 1952, having first checked that it attacked only *A. adenophora* (DSIR files). The gall fly established easily and populations increased greatly during 1953 causing immediate reduction in plant vigour and abundance. During 1954 all populations of the newly introduced gall fly declined because of attack by resident parasitoids, especially an unidentified *Megastigmus* sp. (Hymenoptera: Torymidae) which accounted for 90% of the parasitism. Between 1954 and 1961 parasitism rarely fell below 30% and often exceeded 70% (Dodd 1961).

A leaf spot fungus, *Cercospora eupatorii* Peck, was isolated in August 1954 from *A. adenophora* at a gall fly release site in Queensland. It seems certain that fungus spores were imported from Hawaii on the adult flies.

Despite suppression of the gall fly by parasitoids in Australia, partial control of *A. adenophora* has been achieved. The rapid spread of the weed was halted and existing infestations were reduced in both vigour and density. Seedling growth is now less abundant than it was. This decline has been attributed to attack by *P. utilis*, assisted particularly by *C. eupatorii*.

Importations, Releases and Recoveries

The decision to import *P. utilis* into New Zealand was made in 1957. The likelihood of complete control of *A. adenophora* in New Zealand was thought to be even greater than in Hawaii or Queensland because New Zealand has few gall-forming insects, and therefore few parasitoids which could attack the *P. utilis* galls. The risk of importing the fungus *C. eupatorii* along with the fly was carefully considered (DSIR files). The consequences of introducing the fungus were thought to be slight because it only attacks *Ageratina* species and because it was likely to introduce itself into New Zealand anyway (DSIR files).

Three shipments of stem gall fly adults, *P. utilis*, were received from Queensland in October 1958 (Table 55.1). Of the 621 sent, 580 survived. These were liberated at two sites near Colville, on the Coromandel Peninsula, within 72 hours of despatch from Brisbane (Hoy 1960). Within three months, isolated galls could be found 45 m from one of the liberation sites, and by July 1959, plants 280 m away carried galls. By 1963, *P. utilis* had spread naturally throughout the peninsula, and was then released and established in all large stands of the weed in New Zealand (DSIR files).

Table 55.1 Consignments of *Procecidochares utilis* received from Queensland, Australia, 1958. Flies were released one day after receipt.

Consignment	Despatched from Brisbane	Received in Auckland	Number of flies sent	Number of flies released
1	13 October	15 October	300	288
2	20 October	21 October	188	165
3	27 October	29 October	133	127

Cercospora eupatorii was first recorded in New Zealand in 1962 (Dingley 1965). The origin of the fungus is not certain, but it was probably introduced along with *P. utilis* .

Evaluation

Although galls were originally quite rare, Hoy (DSIR files) recorded that flowering of the weed at the release site had been completely suppressed only five years after the releases were made. In late 1964 control in the same area was described as spectacular, with stands of the weed having been reduced to very small clumps over an area of 2,000 ha (DSIR files). At another site, galls were described as 'extremely numerous on all *A. adenophora* plants, which incidentally looked very sick and showed many withered and dead sticks'. Throughout the Coromandel Peninsula the effect on the weed was described as 'patently deleterious' (DSIR files).

For many years *P. utilis* appeared to be free of the parasitoids which limited its success in Queensland. Two thousand adult flies were reared from galls in 1963 but only 12 unidentified pteromalid parasitoids were recorded. In September 1964, some parasitism was recorded but was regarded as a very minor problem (DSIR files). In 1972 and 1973, however, R.A. Cumber (unpublished DSIR files) sampled galls from seven sites and found that the torymid parasitoid, *Megastigmus* sp. (Hymenoptera: Torymidae) caused significant parasitism of fly pupae ranging from 0 to 71%, with a mean over all sites and all seasons of 31.5%. Only the one parasitoid was recorded. This is the same species which Dodd (1961) recorded attacking a high proportion of *P. utilis* in Queensland and which was responsible for reducing the impact of the control agent there (I. Naumann pers. comm.).

The leaf spot fungus *Cercospora eupatorii* also occurs throughout the range of *A. adenophora* in New Zealand, but its impact on the weed is entirely unknown.

Conclusions

It appears that *P. utilis* caused significant damage to stands of the weed for approximately five years after its introduction, although damage was probably never as severe as that observed in drier regions of Hawaii. The fly does not perform well in moist climates (Bess & Haramoto 1972) and New Zealand conditions may not have suited this species. The abundance and importance of *A. adenophora* has declined in the last 25 years. The severity of gall fly attack on the weed recorded in the first 10 years following releases suggests that the decline in the importance of the weed may have been caused by the attack of *P. utilis*, assisted by the fungus *C. eupatorii* , but no detailed evaluation of the role of either species in the population dynamics of this plant has been carried out. Decline in the importance of *A. adenophora* may also reflect changes in land management which have made the habitat less suitable for the weed.

The abundance of *P. utilis* today also appears to be less than that observed soon after it was released. This may reflect the decreased abundance of the weed, especially in dry open areas, or suppression of the gall fly by *Megastigmus* sp. How and when this parasitoid migrated from Australia is unknown, but the first reliable record of the species is January 1972, 14 years after the gall fly was imported. The relationship between the unidentified pteromalid parasitoid reared from galls of *P. utilis* and the gall fly is unknown (DSIR files).

A. adenophora remains a common plant in the north of the North Island but is even less economically important now than it was in 1957. It is rarely a problem on agricultural land and is most common on roadsides and forest margins. It is unlikely to be the subject of a future biological control project, but the role of both control agents in the suppression of the weed should be studied further.

Literature Cited

Bess, H.A.; Haramoto, F.H. (1958) Biological control of pamakani, *Eupatorium adenophorum*, in Hawaii by a tephritid gall fly, *Procecidochares utilis*. 1. The life history of the fly and its effectiveness in the control of the weed. *Proceedings of the tenth International Congress of Entomology 1956* 4, 543-548.

Bess, H.A.; Haramoto, F.H. (1972) Biological control of pamakani, *Eupatorium adenophorum*, in Hawaii by a tephritid gall fly, *Procecidochares utilis*. 3. Status of the weed, fly and parasites of the fly in 1966-71 versus 1950-57. *Proceedings of the Hawaiian Entomological Society* 21, 165-178.

Dingley, J.M. (1965) New records of fungus diseases on plants in New Zealand, 1962 – 64. *New Zealand journal of agricultural research* 8, 905-920.

Dodd, A.P. (1961) Biological control of *Eupatorium adenophorum* in Queensland. *The Australian journal of science* 23, 356-365.

DSIR, Entomology Division, file BC 1/4.

Hoy, J.M. (1960) Establishment of *Procecidochares utilis* Stone (Diptera: Trypetidae) on *Eupatorium adenophorum* Spreng. in New Zealand. *New Zealand journal of science* 3, 200-208.

Taylor, R.L. (1981) Weeds of roadsides and waste ground in New Zealand. R.L. Taylor, Nelson. 176 pp.

Algal blooms

D.K. ROWE

Pest Status

Blooms of algae, particularly species of the Cyanophyceae (blue-green algae) have created problems in ponds and lakes in many countries. Such blooms are common in warm, nutrient-enriched waters (Reynolds & Walsby 1975), and quickly change the appearance of water, turning it a milky green or brown colour. If the bloom collapses, decomposition of algal cells causes water to become tainted and foul odours are produced. This decline in water quality discourages bathing and prevents the water from being used for drinking (Fogg *et al.* 1973).

The deterrent effect of algal blooms may be due mainly to their appearance but there is good reason for avoiding unsightly waters. Both cattle and humans have been rapidly poisoned after drinking water contaminated by blue-green algae species (Gorham 1964). Both *Microcystis aeruginosa* Kützing and *Anabaena flos-aquae* (Lyngbye) Brébisson are known to produce potent neuro-toxins and, although toxicity of blooms varies, cases of poisoning appear frequent in the United States, South Africa and New Zealand (Fogg *et al.* 1973). McBarron & May (1966) reported the poisoning of sheep in New South Wales, Australia, by *Anacystis cyanea* (Kütz). Drouet & Dally, and Flint (1966) cited *Microcystis* sp. as the cause of lamb deaths in Hawke's Bay. Carruthers (1986) reported two instances where the death of 9-10 cattle had been linked to drinking water contaminated by blue-green algae.

The limited information available on the distribution of blue-green algal species and the occurrence of blooms in New Zealand waters is reviewed by Pridmore & Etheredge (1987). It is apparent that *Anabaena flos-aquae* and *M. aeruginosa* are found throughout New Zealand and that blue-green algal blooms can occur in most nutrient rich waters throughout the country. Blooms are more prevalent in the North Island and no *M. aeruginosa* blooms have been reported in the South Island. These differences may reflect the warmer climate in the north but at this stage studies of blue-green algae are still in the inventory stage (Pridmore & Etheredge 1987). Massive development of blooms is possible in waters where spring concentrations of phosphorus and nitrogen exceed 10 mg/m^3 and 200-300 mg/m^3 respectively (Vollenweider 1968). Waters likely to be affected in New Zealand include many farm ponds, heavily used duck ponds in public reserves and secondary oxidation ponds. Eutrophic lakes would also be susceptible to such blooms.

Background

Although the poisoning of stock after drinking contaminated water is undoubtedly a problem in New Zealand waters, its extent or magnitude is unknown and initial concerns with blue-green algae in this country centred around effects on water quality and fisheries. Blue-green algal blooms are often associated with fish kills (Sawyer *et al.* 1968) and although toxins may be involved in some of the mortalities, oxygen depletion is likely to be the main factor. Oxygen levels are usually already low in the nutrient-enriched waters where blooms form, but respiration by the massive bacterial populations that decompose dying cells of blooms reduces oxygen levels below the threshold for fish survival. This is of particular concern for the maintenance of trout fisheries in eutrophic waters.

In the mid-1960s, low oxygen levels accompanying eutrophication of Lake Tutira, Hawke's Bay, were causing problems with the management of the rainbow trout fishery (Burnet 1983). E. Prowse, Director of the Commonwealth Fish Culture Laboratory in Malaysia, visited New Zealand in 1966 and suggested that algal blooms in Lake Tutira could be controlled by silver carp, *Hypophthalmicthys molitrix* (Cuvier & Valenciennes) (Cyprinidae). This fish is a planktivore and eats mainly blue-green algae.

Prowse (1969) assumed that cropping of the algae would improve oxygen levels and that this would resolve problems with the fishery. Oxygen levels of less than 3 ppm restrict the depth distribution of trout, thus reducing foraging space and feeding opportunities (Rowe 1984). However, the assumption that cropping of algae would improve oxygen levels is tenuous as algal cells are a major source of oxygen. Nevertheless, the assumptions were accepted and in 1969 the Hawke's Bay Acclimatisation Society (managers of the trout fishery in Lake Tutira) obtained permission to import a trial shipment of *H. molitrix* from Malacca.

Following importation the fish were kept under quarantine until 1973 when disease clearance was given by the Ministry of Agriculture and Fisheries (MAF). In 1978, the task of evaluating these fish was handed over to the MAF.

Importations, Releases and Recoveries

The Hawke's Bay Acclimatisation Society imported 35 *H. molitrix* which were quarantined in a hatchery in Napier, and treated for parasites and diseases. All survived and a further shipment of 1,000 was imported in 1970 but only 94 of these survived (Carruthers 1986). Further introductions were not permitted.

Following disease clearance in December 1973, 25 *H. molitrix* were transferred to a floating cage in Lake Orakai. This 4 ha lake, situated 500 m south west of Lake Tutira, was considered a suitable trial site because, like Lake Tutira, it was eutrophic, had algal blooms every summer, and would have a similar climate to Lake Tutira. The 25 fish caged in Lake Orakai grew quickly to 5 kg and provided a brood stock for the production of more silver carp. In 1977, following induced spawning by sex hormone injection, fertilised eggs were obtained and fry produced in the hatchery at Napier.

In 1978, MAF took charge of the evaluation and in September of that year 1,500 juveniles were released into Lake Orakai (Carruthers 1986). Further stockings, each of 2,000 fish, were made in 1979 and 1981. Water quality parameters and growth rates of fish were measured until 1982 when the trial ceased. Fish were not recovered and, as they cannot breed in lakes, will eventually die out.

In February 1981, 600 fish were released into a pond at Te Aute Boys College, Hawke's Bay (Carruthers 1982). This 3 ha pond was an oxidation pond used in the secondary treatment of waste effluent. This trial continued until 1983 and, as the fish died of low oxygen levels each year during August-September (Fisheries Research Division 1983), further stockings are assumed to have been made annually.

In October 1981, 100 *H. molitrix* were stocked into Eland Lake in inland Hawkes Bay to determine whether they could control the summer blooms of *Microcystis* sp. (Fisheries Research Division 1983).

Evaluation

Before the release of *H. molitrix* into Lake Orakai, the lake was divided into experimental and control sections by a barrier net (Carruthers 1979). Bloom formation was assessed by photographic surveys and a range of water quality parameters were also monitored. Experimental and control areas were reversed in 1979, and results from this trial are reported by Carruthers (1986).

Photographic evidence shows that at times there was a spectacular improvement in the appearance of surface water in the experimental section compared to the control, but data on the occurrence and duration of such improvements are lacking. Data on algal biomass are also lacking and the visual differences between the two sections may be due to a disparity in algal depth distribution between the control and experimental areas. However, measurement of light extinction coefficients showed that chlorophyll 'a' levels were consistently lower in the experimental sections (Burnet & Carruthers 1986). Browsing by fish reduced the magnitude of the oxygen fluctuations over the five years, and higher oxygen levels occurred more frequently in the trial areas, mainly in spring and summer when silver carp fed actively. Fish kills related to low oxygen levels were restricted to the control area and it is clear that *H. molitrix* reduced the risk of such incidents.

The trial in the Te Aute Boys College oxidation pond (Carruthers 1982) showed that fish survival was limited to the months of October to July (Fisheries Research Division 1983). Analyses of phosphorus and nitrogen levels in *H. molitrix* indicated that recovery rates of 6.4 kg phosphorus per tonne and 26.2 kg nitrogen per tonne could be expected when these fish are used for nutrient recycling (Carruthers 1986).

The 100 silver carp stocked into Eland Lake in 1981 may have been responsible for the absence of *Microcystis* sp. blooms in the summer of 1983 (Fisheries Research Division 1983) but this may have been caused by other factors.

Evaluations of potential environmental impacts of silver carp are limited. Carruthers (1986) reported that the floating strings of faeces produced by silver carp could create an unsightly appearance. Macrophyte growth may also become a nuisance if water clarity is improved, but these potential problems are viewed as minor in comparison with the benefits of algal bloom control (Carruthers 1986).

Silver carp ingest zooplankton and several reports, e.g. Cremer & Smitherman (1980), indicate that organisms larger than 1 mm are excluded. It is not known if they are damaged when sorting occurs on the gill rakers. Some smaller zooplankters apparently pass through the gut unharmed (Barthelmes & Jahnichen 1978, Spartaru 1977) but it is not clear whether all species, particularly juvenile copepods and small cladocera, are unharmed by this experience. Blue-green algae are notoriously difficult to digest and strongly acidic conditions are required to break down their cell walls (Moriarty 1973). It is difficult to reconcile the observations on zooplankton passage with such a digestive process. There are no reports dealing with the effects of silver carp browsing on natural populations of zooplankton, and effects of *H. molitrix* on native and introduced fish populations in New Zealand have not been evaluated.

Conclusions

H. molitrix was suggested as a means of biological control for algal blooms by Prowse (1969). It has been successfully used to control algal blooms in Singapore (Buck 1977) but despite this there has been little evaluation of its use for controlling algal blooms in other waters (Henderson 1983). Results obtained in New Zealand indicate that it can provide a degree of control, and that some improvement in water quality can be expected. The main trial in New Zealand was conducted in a hyper-eutrophic environment, and greater improvements might be obtained in less eutrophic waters, particularly with higher stocking densities.

If silver carp significantly reduce blue-green algal biomass in other New Zealand waters, the changes in phytoplankton species composition can be expected to have ramifications at the secondary and tertiary trophic levels. As yet there is no indication of what will happen to zooplankton or fish populations following such changes. Release of *H. molitrix* for use by the public is planned (McCarter 1987) but, because of the lack of data on environmental effects, its initial use may be restricted to waters where fish and wildlife values are low.

H. molitrix has similar breeding requirements to the grass carp *Ctenopharyngodon idella*

Valenciennes (Cyprinidae) and so reproduction is improbable in New Zealand waters except for the Waikato River (see Chapter 58).

Acknowledgement

Studies of silver carp in New Zealand were all carried out by A.D. Carruthers, and this review is a small tribute to his work.

Literature Cited

Barthelmes, D.; Jahnichen, H. (1978) On the food selection of and amounts of food consumed by the silver carp three to four summers old. *Zeitschrift für die Binnenfisheries der DDR* 25, 331-334.

Buck, D.H. (1977) The integration of aquaculture and agriculture. *Fisheries* 2, 11-16.

Burnet, A.M.R. (1983) Oxygen in eutrophic lakes. *Freshwater catch* 18, 22-23.

Burnet, A.M.R.; Carruthers, A.D. (1986) A summary of data-logging results, Lake Orakai 1979-1984. Pp. 41-63 in Carruthers, A.D. Effect of silver carp on blue green algal blooms in Lake Orakai. *New Zealand Ministry of Agriculture and Fisheries, fisheries environmental report* 68, 63 pp.

Carruthers, A.D. (1979) Silver carp field trial sees large weight gain. *Freshwater catch* 3, 12-13.

Carruthers, A.D. (1982) Silver carp in oxidation ponds at Te Aute. *Freshwater catch* 14, 17.

Carruthers, A.D. (1986) Effect of silver carp on blue green algal blooms in Lake Orakai. *New Zealand Ministry of Agriculture and Fisheries, fisheries environmental report* 68, 63 pp.

Cremer, M.C.; Smitherman, R.O. (1980) Food habitat and growth of silver and bighead carp in cages and ponds. *Aquaculture* 20, 57-64.

Fisheries Research Division (1983) Ministry of Agriculture and Fisheries Annual Report.

Flint, E.A. (1966) Toxic algae in some New Zealand freshwater ponds. *New Zealand veterinary journal* 14, 181-185.

Fogg, G.E.; Stewart, W.D.P.; Fay, P.; Walsby, A.E. (1973) The blue-green algae. Academic Press, New York, U.S.A. 459 pp.

Gorham, P.R. (1964) Toxic algae. Pp. 307-336 in Jackson, D.F. (ed.) Algae and man. Plenum Press, New York.

Henderson, S. (1983) Evaluation of filter feeding fishes for removing excess nutrients and algae from waste water. Final report 1977-1980. *Environmental Protection Agency, National Technical Information Service* PB 83 19334.

McBarron, E.J.; May, V. (1966) Poisoning of sheep in New South Wales by the blue-green algae *Anacystis cyanea* Kuetz. *Australian veterinary journal* 42, 449-453.

McCarter, N. (1987) Policy on silver carp. Unpublished report, New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Division. 6 pp.

Moriarty, D.J.W. (1973) The physiology of digestion of blue-green algae in the cichlid fish *Tilapia nilotica*. *Journal of zoology, London* 171, 25-39.

Pridmore, R.D.; Etheredge, M.K. (1987) Planktonic cyanobacteria in New Zealand inland waters: distribution and population dynamics. *New Zealand journal of marine and freshwater research* 21, 491-502.

Prowse, G.A. (1969) The role of cultured pond fish in the control of eutrophication in lakes and dams. *Verhandlungen internationale Vereinigung für theoretische und angewandte Limnologie* 17, 714-718.

Reynolds, C.S.; Walsby, A.E. (1975) Water-blooms. *Biological reviews of the Cambridge Philosophical Society* 50, 437-481.

Rowe, D.K. (1984) Some effects of eutrophication and the removal of aquatic plants by grass carp (*Ctenopharyngodon idella*) on rainbow trout (*Salmo gairdnerii*) in Lake Parkinson, New Zealand. *New Zealand journal of marine and freshwater research* 18, 115-127.

Sawyer, P.J.; Gentile, J.H.; Sasner, J.J. (1968) Demonstration of a toxin from *Aphanizomenon flos-aquae* (L.) Ralfs. *Canadian journal of microbiology* 14, 1199-1204.

Spartaru, P. (1977) Gut contents of silver carp *Hypophthalmichthys molitrix* (Val.) and some trophic relations to other fish species in polyculture system. *Aquaculture* 11, 137-147.

Vollenweider, R.A. (1968) Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorous as factors in eutrophication. Organisation of Economic Cooperation and Development, Directorate of Scientific Affairs, Paris.

Alternanthera philoxeroides (C. Martius) Grisebach, alligator weed (Amaranthaceae)

L.I.N. ROBERTS and O.R.W. SUTHERLAND

Pest Status

Alligator weed is a hollow-stemmed, emergent aquatic plant which is a native of South America east of the Andes. It is thought to have arrived in New Zealand in ships' ballast and was first recorded by Cheeseman in 1906 in the northern Wairoa River, near Dargaville. It is now found from Bay of Islands and Hokianga Counties in the north, to south Auckland (Philip *et al.* 1988, Roberts *et al.* 1983).

Alligator weed grows in shallow water and on the banks of waterways and ponds, spreading across the water in a thick floating mass. In streams and drains it impedes water flow. In times of flood, large mats of weed can break free to block drains and culverts downstream. These heavy free-floating mats can also lodge against bridge piles and fencelines, forming a mass that enmeshes other debris. In time, the combined mass can create such pressure that piles are weakened and fences can be washed away. In ponds and dams the weed makes access to the water difficult for stock and greatly reduces the quality of water for both stock and birdlife. The subsequent trampling, pugging and deterioration of the bank edges also encourages other weeds such as willow weed (*Polygonum* spp.) and rush (*Juncus* spp.) to colonise the area (Philip *et al.* 1988, Roberts *et al.* 1983, 1984a, 1984b).

Alligator weed also grows on land, mostly in damp areas and on low-lying heavy soils. Because of its rapid growth and scrambling smothering habit, it causes considerable problems in horticultural crops. Cultivation breaks up the plant and spreads it further, and only repeated applications of chemicals with residual soil activity can adequately control it. Although found in many low lying pasture areas, it is readily eaten by stock and so has not been considered a problem in these situations. However, recent trials by the Northern Wairoa Veterinary Service link feeding on this weed to a photosensitivity reaction of stock, especially lambs and calves (Joynt 1987, Philip *et al.* 1988).

Background

Alligator weed reached the southern United States in the 1890s shortly after the arrival of water hyacinth, *Eichhornia crassipes* (Martius) Solms-Laubach (Pontaderiaceae), another South American native. Both plants spread rapidly through the south-eastern coastal states. Since water hyacinth usually outcompeted alligator weed, it was not until the advent of herbicides which gave effective control of water hyacinth that alligator weed was recognised as a serious problem (Coulson 1977). By 1963, 73,800 ha of water in the eight southern states were infested (U.S. Army Corps of Engineers 1965).

Research on biological control began in 1959 and from 1960 to 1974 entomologists were based in South America looking for and testing potential biological control agents (Coulson 1977). Over 40 species of insects were found feeding on alligator weed, and of these three were selected which were considered suitable for introduction into the United States (Coulson 1977). These were *Agasicles hygrophila* Selman & Vogt (Coleoptera: Chrysomelidae), a flea beetle which feeds on the leaves of aquatic alligator weed and pupates in the hollow stem, *Vogtia malloi* Pastrana (Lepidoptera: Pyralidae), a moth whose larvae feed on the stems of aquatic alligator weed as well as on weed on river banks and in swamps, and *Amynothrips andersoni* O'Neill (Thysanoptera: Thripidae), a thrips which feeds on the apical leaves.

When extensive testing both in South America and U.S.A. established that there was no risk of any of these three species feeding on any other plants (Maddox & Resnik 1969, Maddox *et al.* 1971, Simons *et al.* 1968), they were released in the U.S.A. *A. hygrophila* and *Vogtia malloi* rapidly became established and within a couple of years, *A. hygrophila* (in particular) was exerting significant control on the weed at the sites of release (Coulson 1977).

Alligator weed did not reach Australia until the 1940s (Hockley 1974). Because of the threat the weed posed to the country's waterways, *A. hygrophila* and *V. malloi* were imported from the U.S.A. in 1976 (Julien *et al.* 1979). A third species, *Disonycha argentinensis* Jacoby (Coleoptera: Chrysomelidae), was imported from Brazil in 1979 (Julien 1980). All three species were tested thoroughly in Australia against a range of host plants before permission to release was given. *A. hygrophila* and *V. malloi* became established very quickly and brought about dramatic control of the aquatic weed (Julien *et al.* 1979). *D. argentinensis* did not establish (M.H. Julien pers. comm.)

In July 1980, the New Zealand Ministry of Agriculture and Fisheries approached Entomology Division, DSIR, about the possibility of instigating a similar programme in New Zealand. The Noxious Plants Council offered funds for a part time technician for the project while DSIR provided the scientific supervision, facilities and administrative backup. Because of the previous extensive host specificity testing with *A. hygrophila* and *V. malloi* in South America, U.S.A. and Australia and because of the 18 and 11 years' experience respectively with the species as biocontrol agents in the U.S.A. and five years' experience with both species in Australia, it was not deemed necessary to do further specificity testing for these two species here.

Importations, Releases and Recoveries

Agasicles hygrophila Selman & Vogt (Coleoptera: Chrysomelidae)

The Division of Entomology, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, provided *A. hygrophila* which had been collected from the field near Sydney. This field population resulted from releases made in Australia between 1977 and 1979 using a population originally imported from Florida in 1976 (Julien 1980). Two consignments totalling 208 adults were received in October 1981 and January 1982. In both cases the beetles reproduced rapidly and completed a second generation within two months. Details about shipments can be found in Roberts *et al.* (1984a) and about rearing methods in Roberts *et al.* (1984b). No parasitoids or diseases were detected in either culture and approval to remove them from quarantine was granted in December 1981 and March 1982 respectively.

Between December 1981 and March 1984, 32,250 adult *A. hygrophila* and 2,500 larvae were released at 26 sites in Northland and Auckland. Details of these release sites are given in Roberts *et al.* (1984a). Beetle populations generally began increasing immediately following releases except at sites affected by stock feeding, herbicide sprays or floods. Where releases were made early in summer, population increases of 10-20 times often occurred by the onset of colder weather in autumn (Roberts *et al.* 1984b). Survival over the winter period was variable and appeared to be dependent on weed condition, which was in turn affected by the frequency of floods and frosts (Roberts *et al.* 1984b). Beetle populations became established most quickly at sites where the weed was least affected by these factors, principally northern sites and in ponds and dams.

Disonycha argentinensis Jacoby

One shipment of *D. argentinensis*, consisting of approximately 250 adults plus some eggs, was received from the Division of Entomology, CSIRO, on 21 October 1981. These insects

(Coleoptera: Chrysomelidae)

came from a laboratory colony in its ninth (adults) and tenth (eggs) generation which was set up in 1979 using insects imported from Marium, Sergipe, in southern Brazil.

The host-range of *D. argentinensis* was tested in Australia using 37 species of plants (Sands *et al.* 1982) and in New Zealand against a further three species (Roberts *et al.* 1983, 1984a, 1984b). Details of rearing methods and the New Zealand tests are given in Roberts *et al.* (1984a). The host specificity of *D. argentinensis* was confirmed and after five generations in quarantine, field releases began. Between February 1982 and February 1984, a total of 18,700 adults was released at 17 sites in Northland and Auckland, details of which are given in Roberts *et al.* (1984a).

Vogtia malloi Pastrana (Lepidoptera: Pyralidae)

Four shipments of *Vogtia malloi* were received, comprising individuals collected in the field in the Sydney area and air-freighted to Auckland by CSIRO. This field population was the result of releases made in Australia between 1977 and 1979 after insects were imported from the U.S. Department of Agriculture laboratories at Gainesville, Florida, in 1976 (Julien 1980).

The first shipment was received from Brisbane on 20 January 1982 and consisted of alligator weed stems containing larvae and pupae collected in December and January. Unfortunately, this shipment had to be destroyed because many of the stems were rotten and the larvae were infected with the fungus *Aspergillus flavus* Link (Roberts *et al.* 1984a). The second shipment consisted of *Vogtia*-infested stems which were collected in the Sydney area on 18 and 19 December 1983 and immediately shipped to New Zealand. The stems arrived in excellent condition and the emerging insects bred prolifically (Roberts *et al.* 1984a). By late February, more than two generations had passed with no sign of parasitism or pathogens and the insects were released from quarantine. Between late February and early April, infested stems containing approximately 10,000 larvae were released at four sites near Woodhill, Dargaville and Whangarei. Despite these large releases, it was thought that the variability provided by the 47 imported moths was too small on which to base a population so a third shipment was requested. This third shipment was received from Australia on 27 March 1984. In quarantine the insects were divided into three groups, one of which was found in late April to be infested with an unidentified microsporidian. This group was retained in quarantine for another generation at which point the adults were found to be free of pathogens. All the progeny of this shipment were maintained in the laboratory over winter and the same microsporidian, probably brought into the lab on field-collected weed (P. Wigley pers.comm), was again found in one of the groups in mid-June. These were destroyed but progeny of the other two groups were released into the field in early spring 1984.

No *V. malloi* were found to have survived their first winter in the field so in March 1987 C.J. Winks went to Australia to collect further pupae near Sydney in order to establish a disease-free colony (Philip *et al.* 1988). The insects were initially line-bred from original pairs of moths. A proportion of each generation was tested for disease, and lines with infection were discarded. A high proportion of the offspring of 'clean' adults was found to be diseased indicating that the microsporidia were being introduced on the field-collected weed, rather than being transmitted from one generation to the next. Line-rearing was then abandoned but in all subsequent generations, adults were mated in individual pairs and pathogen-tested after oviposition. Only offspring from adults in which no infection was found were used in colony maintenance. Insects released were therefore one generation away from 'clean' adults (Philip *et al.* 1988).

Between August 1987 and February 1988, 12 releases of *V. malloi* were made at ten sites in Northland and Auckland (Philip *et al.* 1988). Each release consisted of approximately 5,000 eggs and/or neonate larvae or 1,000-2,000 second or third instar larvae. Each of the ten sites was visited in the following autumn and *V. malloi* was recovered from seven of the them. At five of these sites, at least one field generation had been completed (Philip *et al.* 1988).

Evaluation

Agasicles hygrophila

A. hygrophila has spread rapidly throughout Northland. Beetle numbers in drains and rivers increase slowly during early summer, but by late summer or early autumn many sites have large populations inflicting considerable damage to the weed. Flash floods, frosts or drought during summer can reduce *A. hygrophila* populations considerably, but with the return of good weed growth the beetles quickly re-establish. On dams and lakes the weed is less affected by flooding or drying out and beetle numbers increase more rapidly. (Philip *et al.* 1988, Roberts *et al.* 1984b). Cage trials demonstrating the significant effect of *A. hygrophila* on dry weight of weed are reported by Roberts *et al.* (1984a, 1984b).

A detailed study of *A. hygrophila* activity in Hobson County was carried out between December 1986 and April 1987 (Joynt 1987). This showed that in four years, the insect had spread from eight isolated release sites to all known aquatic alligator weed infestations in the county (Philip *et al.* 1988). Realised or potential savings from the action of *A. hygrophila* were found to be considerable (Joynt 1987, Philip *et al.* 1988). To maintain water flow, 237 km of water board drains in Hobson County are usually sprayed with herbicide twice each year (at a cost of NZ$800/km/year) and mechanically cleared once each year (NZ$400/km). Alligator weed is responsible for approximately 20% of weed problems in the drains but in two 200 m drains infested only with alligator weed, *A. hygrophila* negated the need for weed control during the summer of 1986/87. If the action of *A. hygrophila* could render a second spraying unnecessary in just 20% of the drains in this county, NZ$19,000 would be saved each year (Joynt 1987, Philip *et al.* 1988).

In rivers and streams, the action of *A. hygrophila* helped maintain water flow. During the survey, a planned clearance of 2 km of river at a cost of NZ$7,000 was not carried out, mainly due to the destruction of alligator weed mats by *A. hygrophila*. Less damage by weed mats washed away during floods could also be expected (Joynt 1987, Philip *et al.* 1988).

In Hobson County there are approximately 100 farm dams infested with alligator weed. In dams with light infestations of weed, the beetle has prevented the formation of floating mats, thereby slowing down pugging of dam edges and preventing deterioration of water quality. Farm dams are normally mechanically cleared every seven to eight years at an average cost of approximately NZ$500 each. The action of *A. hygrophila* could extend this to 10-12 years, by which time clearance would be required because of other weeds (Joynt 1987, Philip *et al.* 1988).

North of Hobson County, at Whatatiri, the Whangarei Acclimatization Society has developed a 3.5 ha lake for wildlife management of which approximately 1.9 ha, the shallower parts, have become covered with alligator weed. A total of 3,900 adults and larvae was released here in December 1982 and March 1983, and the population rapidly increased. In February 1984, a population estimate based on quadrat counts every 10 m along seven transects across the lake gave a mean of 309 adults/m^2 of weed or approximately 5.8 million over the whole lake, with lesser numbers of other stages (Roberts *et al.* 1984b). Most of the weed was severely damaged (much of it totally defoliated) and eaten down to the surface of the water. A similar pattern has been repeated in subsequent years (B. Miller pers. comm.). Spring weed growth is lush but by late summer defoliation is advanced and damage increases progressively until the onset of winter. The lake is now relatively free of above-water weed by the beginning of the duck-shooting season in May. Herbicide spraying has been discontinued since the beetles were released but a greater degree of weed control earlier in spring would increase the surface area available to ducks during the breeding season. Spread of the weed mat to uninfested areas has been checked since the establishment of *A. hygrophila* on the lake.

Disonycha argentinensis

When *D. argentinensis* was approved for release in February 1982, it was too late in the season to establish extensive trials. However, four cages were established at Kaipara, two

containing 150 beetles and two without beetles. Live adults were found in the cages until September but then the remaining beetles died. In January 1983, a more extensive replicated trial was set up in a weed-infested pasture at Woodhill. Cages covered in fine gauze enclosing 0.5 m^2 and containing 0, 20 or 40 pairs of beetles were established. At monthly intervals, the insects were counted and the dry weight of weed was measured in replicate cages of each density. Eggs and pupae were found in the soil and adults and larvae tended to hide around the base of the plant during daytime. These were sampled by searching the foliage in selected cages then digging up the weed and sieving the soil. From the first sample on, there was no significant difference in either insect numbers or weed dry weight between the cages set up with 40 or 80 beetles so the results for these two densities were pooled. Larvae, prepupae, and pupae were found so reproduction was occurring but in all cages population levels dropped quickly. From a mean of 60 beetles per cage at the end of January, a mean of only 17 eggs, larvae and adults was recovered per cage after one month, 22 after two months, 20 after three months and 15 after four months. However the insects did have a noticeable effect on the weed, with a significant difference in weed dry weight between the infested and the control cages recorded from the outset. The insect population did not persist after the last cages were removed in late May.

Although *D. argentinensis* behaviour made it difficult to locate in the field, even intensive searching at release sites on subsequent visits yielded no *D. argentinensis*, and no damage that was definitely due to them was observed. Although the gauze-covered cages were intended to replicate field conditions as closely as possible, the reduced air flow meant temperature and humidity within the cages was slightly higher than ambient and the weed growth slightly more luxuriant. The improved survival inside cages (although still not over the winter period) may indicate that *D. argentinensis* requires warmer or more humid conditions than are available in Northland and Auckland or in eastern Australia.

Vogtia malloi

In both U.S.A. and Australia, *V. malloi* is believed to make an important contribution to the successful control of alligator weed, in particular by exerting pressure on weed growing on river banks and swamps and other areas too dry for *A. hygrophila* (Coulson 1977, Julien *et al.* 1979). Since climatically and geographically similar habitats exist in New Zealand, there is no obvious reason why this species should not survive here and it is possible that the establishment failure of the 1984 releases was a result of an undetected infection. It appears that the 1988 releases have completed at least one generation in the field but it is too early yet to determine whether they have successfully established.

Conclusions

A. hygrophila is well established in most of the areas in New Zealand where alligator weed is found. Its efficacy in controlling the weed at any given site in any one season depends on conditions experienced at that site, such as frosts, flooding, drying out, stock management, and herbicidal or mechanical clearance of the weed. It is already providing economic and environmental benefits (Philip *et al.* 1988). If *Vogtia malloi* is able to establish, it should complement the action of *A. hygrophila* in reducing the level of alligator weed infestations (Philip *et al.* 1988, Roberts *et al.* 1984b).

Acknowledgements

This project was made possible by financial contributions from the Noxious Plants Council, the Auckland Regional Water Board and District Noxious Plants Authorities throughout New Zealand. It was also made possible by the dedicated assistance of Chris Winks and Derrith Bartley.

Literature Cited

Coulson, J.R. (1977) Biological control of alligator weed, 1959-1972. A review and evaluation. *Technical bulletin, United States Department of Agriculture* 1547.

Hockley, J. (1974) ... and alligator weed spreads to Australia. *Nature* 250, 704.

Joynt, P. (1987) Biological control of alligator weed. The results and benefits of introducing *Agasicles hygrophila* in the Hobson County. Internal report, Hobson District Noxious Plants Authority. 33 pp.

Julien, M.H. (1980) Control of aquatic *Alternanthera philoxeroides* in Australia; another success for *Agasicles hygrophila*. *Proceedings of the Fifth International Symposium on the Biological Control of Weeds, Brisbane, Australia*, 583-588.

Julien, M.H.; Broadbent, J.E.; Harley, K.L.S. (1979) The current status of biological control of *Alternanthera philoxeroides* in Australia. *Proceedings of the 7th Asia-Pacific Weed Science Society Conference*, 231-235.

Maddox, D.M.; Resnik, M.E. (1969) Determination of host specificity of the alligator weed flea beetle, *Agasicles* n. sp., with radioisotopes. *Journal of economic entomology* 62, 996-999.

Maddox, D.M.; Andres, L.A.; Hennesey, R.D.; Blackburn, R.D.; Spencer, N.R. (1971) Insects to control alligator weed – an invader of aquatic ecosystems in the United States. *BioScience* 21, 985-991.

Philip, B.A.; Winks, C.J.; Joynt, P.W.; Sutherland, O.R.W. (1988) Current status of biological control of alligator weed in New Zealand. *Proceedings of the 41st New Zealand Weed and Pest Control Conference*, 61-65.

Roberts, L.I.N.; Winks, C.J.; Bartley, D. (1983) Biological control of alligator weed. Pp. 55-59 in *Proceedings of the Aquatic Weeds Seminar, Massey May 1983*. Agricultural and Horticultural Sciences Extension, Massey University.

Roberts, L.I.N.; Winks, C.J.; Sutherland, O.R.W. (1984a) Biological control of alligator weed: report for the period July 1980 – April 1984. Internal report, Entomology Division, DSIR. 29 pp.

Roberts, L.I.N.; Winks, C.J.; Sutherland, O.R.W.; Galbreath, R.A. (1984b) Progress of biological control of alligator weed in New Zealand. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 50-54.

Sands, D.P.A.; Kassulke, R.C.; Harley, K.L.S. (1982) Host specificity of *Disonycha argentinensis* (Col.: Chrysomelidae), an agent for the biological control of *Alternanthera philoxeroides* (alligator weed) in Australia. *Entomophaga* 27, 163-172.

Simons, J.N.; Silverstein, R.M.; Bellas, T. (1968). Test of a feeding stimulant in alligator weed for *Agasicles* n. sp. *Journal of economic entomology* 61, 1448-1449.

U.S. Army Corps of Engineers (1965) Expanded project for aquatic plant control. *U.S. House of Representatives, 89th Congress, 1st Session, House document* 251, 148 pp.

Aquatic macrophytes, waterweeds

D.K. ROWE and R.L. HILL

Pest Status

Aquatic macrophytes cause problems in waterways in many parts of the world (Holm *et al.* 1970). In New Zealand the growth of aquatic macrophytes in streams and rivers impedes drainage and causes flooding. In lakes, aquatic weeds restrict swimming and angling activities as well as navigation. Following storms, large masses of rotting vegetation are washed on to shorelines and amenity values of beaches are spoiled. Macrophytes are also a problem in hydro-electric reservoirs such as the lakes of the Waikato River, where their detached stems float down-river to block water-intake screens of power stations resulting in loss of electricity production or damage to generating equipment (Coffey 1975). Eady (1972), Hughes (1976) and Rowe & Schipper (1985) have estimated some of the economic costs of weed control measures used in New Zealand waters and their figures provide an indication of the extent and size of the problem.

The main species of macrophytes currently causing problems in New Zealand waters are listed in Table 58.1. They can be categorised as:

-floating species found on the surface of static waters such as farm ponds

-submersed macrophytes which grow from soft substrates around the shores of lakes and river margins

-emergent macrophytes which frequent streams, drainage channels and wetlands.

In general, problems have arisen with the submersed species because they have replaced the shallow, low-growing native plants with dense surface-growing stands of vegetation. Whereas much attention has been focussed on the impacts to recreation and water use caused by the extensive surface growths of the submersed species there has been little study of impacts to aquatic faunas beyond those of Fish (1963, 1966) in lakes and those of Burnet (1972) and Marshall & Winterbourn (1979) in streams. Studies of the ecology of the main problem species have been conducted by Coffey (1970, 1974) and Brown (1975).

The introductions of these plants into New Zealand have not been well documented. However, much of the information on their arrival and dispersal is reviewed by Howard-Williams *et al.* (1987). While their spread into previously unaffected water bodies continues, the arrival of new species appears to have ceased. Species which produce seeds (e.g. *Ottelia ovalifolia* (R. Brown) L. C. Richard (Hydrocharitaceae) and *Aponogeton distachyus* L. f. (Aponogetonaceae)) have spread rapidly, colonising waters throughout the country. The 'oxygen weeds' (*Elodea canadensis* Michaux, *Lagarosiphon major* (Ridley) Moss ex Wager and *Egeria densa* Planchon (Hydrocharitaceae)), which do not set seeds, spread within lakes by vegetative growth from plant fragments and their dispersal between water bodies is occurring more slowly, mainly by physical transfer of bud-bearing fragments on trailer-borne boats (Johnstone *et al.* 1985). Nevertheless, *Elodea canadensis* is now present in many New Zealand lakes with either *Egeria densa* or *L. major* also occurring in many of the larger North Island lakes and reservoirs. The introduction and spread of the emergent species which cause problems in drainage and irrigation channels is less well documented than that of the submersed species. Eady (1972) reported on problems with aquatic weeds in New

Table 58.1 Main problem species of aquatic macrophytic plants present in New Zealand waters.

SURFACE-FLOATING SPECIES	
Azolla pinnata R. Brown	Salviniaceae
Salvinia molesta Mitchell	Salviniaceae
Spirodella punctata (G.F.W. Meyer) C.H. Thompson	Lemnaceae
SUBMERSED SPECIES	
Ceratophyllum demersum L.	Ceratophyllaceae
Egeria densa Planchon	Hydrocharitaceae
Elodea canadensis Michaux	Hydrocharitaceae
Hydrilla verticillata (L. f.) Royle	Hydrocharitaceae
Lagarosiphon major (Ridley) Moss ex Wager	Hydrocharitaceae
Vallisneria spiralis L.	Hydrocharitaceae
EMERGENT SPECIES	
Alternanthera philoxeroides (C. Martius) Grisebach	Amaranthaceae
Apium nodiflorum (L.) Lagasca	Apiaceae
Aponogeton distachyus L. f.	Aponogetonaceae
Callitriche stagnalis Scopoli	Callitrichaceae
Glyceria fluitans (L.) R. Brown	Poaceae
G. maxima (Hartm.) Holmberg	Poaceae
Juncus articulatus L.	Juncaceae
Ludwigia spp.	Onagraceae
Mimulus guttatus DC.	Scrophulariaceae
Myriophyllum aquaticum Velloso Verdcourt	Haloragaceae
Rorippa nasturtium-aquaticum (L.) Hayek	Brassicaceae
R. microphylla (Reichb.) Hylander	Brassicaceae
Ottelia ovalifolia (R. Brown) L.C. Richard	Hydrocharitaceae

Zealand drainage systems and more recently Rowe & Schipper (1985) listed the farm ponds, small lakes, water reservoirs, streams and drainage channels throughout New Zealand for which control of submersed and emergent species had been requested. It is apparent that the problem species of both submersed and emergent macrophytes are now widespread throughout most of the North Island as well as parts of the South Island. In 1982, in order to control their spread, *Egeria densa*, *L. major*, *Ceratophyllum demersum* L. (Ceratophyllaceae), *Hydrilla verticillata* (L. f.) Royle and *Vallisneria spiralis* L. (Hydrocharitaceae) were designated noxious plants under the Noxious Plants Act 1978. Later, in 1984, *Salvinia molesta* Mitchell (Salviniaceae) was classified as a Class A noxious plant and a programme was instigated to identify and eradicate all populations in New Zealand.

Background

Floating, emergent and submersed macrophytes can all be destroyed by herbicides, but except for the floating species, eradication or long term control by this method is rarely practicable. Paraquat has been used to eliminate *Salvinia molesta* from two sites (Howard-Williams *et al.* 1987) and to control *Elodea canadensis* in streams (Burnet 1972). Diquat is currently used in recreational water such as the Rotorua lakes to control *Lagarosiphon major*. Because of the high cost of herbicides, the difficulties of using them successfully, and their potential impact on other biota, they are mainly used to treat localised areas of weed growth which are causing acute problems.

Detached floating stems in hydro-electric reservoirs are intercepted by floating booms and screens. This is proving effective, especially coupled with lowering of reservoir water levels to desiccate submersed plants. However, lowering of water levels can also be expected

to devastate the littoral zone faunas, with adverse implications for wildlife and fisheries. As yet this ecological cost has not been evaluated.

In drainage channels, flowing waters limit the effectiveness of herbicides. The main form of weed control in these waters is therefore mechanical harvesting from the bank. This is expensive, damages pasture and is exacerbating weed growth. The progressive widening of drains means that eventually channels have to be cleaned from both banks, thus doubling costs.

Native aquatic herbivores such as *Nymphula nitens* Butler have not proven capable of controlling the introduced macrophytes. Introduced animals, such as black swan (*Cygnus atratus* (Latham)) and rudd (*Scardinius erythrophthalmus* L.), also feed extensively on the problem species, but have failed to demonstrate any control potential. Other exotic herbivores were therefore considered as possible biological control agents.

F.D. Bennett (DSIR files) summarised the control agents available for the biological control of water weeds, particularly *Ceratophyllum demersum*. He found that the Brazilian snail *Marisa cornuarietis* L. (Ampullaridae) had been used for weed control overseas (Seaman & Porterfield 1964) and appeared to be the most promising candidate. He pointed out, however, that the snail could feed on many other aquatic plants, including watercress and rice seedlings, was an active predator of the eggs and juveniles of other snails and that some strains of the snail carried the cercaria of parasitic flukes. He also questioned whether this tropical or sub-tropical species could breed in the relatively cool waters of the Waikato river system. Despite these reservations, Bennett recommended that *M. cornuarietis* should be introduced into New Zealand for evaluation in the laboratory (DSIR files).

By the mid-1960s several weed eating fish, including the European carp, *Cyprinus carpio* L. (Cyprinidae), various *Tilapia* species and particularly the grass carp *Ctenopharyngodon idella* Cuvier & Valenciennes (Cyprinidae) had been used for aquatic weed control overseas. It was found that *Cyprinus carpio* reproduced readily and the large populations that were quickly established created water quality problems. Once established they could not be eliminated and became major pests in many North American and Australian waters. It was considered likely that *Tilapia* species would breed in New Zealand and subsequently could have an impact on native fish populations. As a result, both of these species were rejected as potential candidates for weed control in New Zealand waters. At the same time, the grass carp was attracting much attention in North America because of its broad-spectrum weed eating ability, and its specific reproductive requirements, which meant it was unlikely to breed in temperate countries. By the late 1960s *Ctenopharyngodon idella* was the main species being evaluated for weed control in Europe and North America (Shireman & Smith 1981). In October 1966, E. Prowse, Director of the Commonwealth Fish Culture Laboratory in Malaysia, visited New Zealand and reported on the weed problems in Lake Rotorua for a government inter-departmental meeting. He recommended trials with *C. idella* because of its weed eating capacity, and because it was unlikely to interfere with other fish in New Zealand waters, or breed.

Importations, Releases and Recoveries

Marisa cornuarietis L. (Ampullaridae)

In 1967 and 1968, four shipments totalling 480 snails were sent from the Trinidad Station of the CIBC to V.J. Chapman of the Botany Department, University of Auckland (Cock 1985). No snails survived in the first two shipments (Chapman 1970). Twenty snails survived in the third shipment but these died within four months. The fate of the fourth shipment is unknown. All snails were contained in a closed system indoors and were never released. The project was discontinued because of uncertainty about the ability of the snail to control water weeds in New Zealand and the environmental risks involved (Brown 1975).

Ctenopharyngodon idella Cuvier & Valenciennes (Cyprinidae)

The first consignment of *C. idella* was imported into New Zealand in May 1966 by V.J. Chapman. Most of these fish died and none was released. Eight fish were imported to New Zealand in 1967 and a further six in 1969. These were all kept at the Botany Department, University of Auckland, where aquarium and pond experiments established that they would eat the problem weeds found in New Zealand lakes (Chapman & Coffey 1971). All fish were presumably destroyed or died after these experiments. Following these limited introductions, controversy arose over the importation and possible use of grass carp in New Zealand. Chapman (1970) indicated that the trout angler's fears were misplaced due to confusion between *C. idella* and *Cyprinus carpio*. Nevertheless opposition continued.

The Fisheries Research Division of the Ministry of Agriculture and Fisheries (MAF) was asked to evaluate *Ctenopharyngodon idella* for weed control in New Zealand (Waugh 1971). In 1971, 2,000 fingerlings (2-3 cm long) were air-freighted to New Zealand from Hong Kong and were transferred to secure quarantine ponds at the Division's Rotorua laboratory. Only 500 fish survived the preliminary handling and treatment to eliminate foreign disease organisms and parasites (Edwards & Hine 1974). Of six parasites found on these fish, five were exotic and two, *Lernaea cyprinacea* L. (Copepoda) and *Bothriocephalus gowkongenesis* Yeh, could have posed a threat to established fish populations. These were all eliminated from the stocks.

Following initial aquarium and pond investigations (Edwards 1973, 1974) a small trial was conducted in a 690 m long section of a drainage ditch on the Rangitaiki Plains (Bay of Plenty). In 1973, 45 fish were released into the ditch and escape was prevented by screens. All fish left alive were later recovered (Edwards & Moore 1975).

Further trials were dependent on the production of more grass carp in New Zealand. By 1976, techniques for artificial propagation had been developed (Mitchell 1979), and in 1980 sufficient fry had been produced to allow shipments of 15,000 to be sent to Fiji for weed control in the Rewa River (Mitchell 1982).

The Freshwater Fisheries Advisory Council had established guidelines for the introduction of freshwater fish into New Zealand (McDowall 1979) and in accordance with these, further trials were started in two small lakes (Mitchell 1980). One of these was Parkinsons Lake, a 1.92 ha eutrophic sand-dune lake, west of Pukekohe. The other trial site was a 2 ha water supply reservoir north-west of Waihi Beach. In comparison with Parkinsons Lake, which contained introduced fish species including rainbow trout, the Waihi Beach reservoir contained only native species of fish. In total, 60 grass carp were introduced into Parkinsons Lake between 1975 and 1977, and 100 into the Waihi Beach reservoir. By 1978, all weed beds were virtually eliminated in both trial areas (Mitchell 1980). All remaining grass carp were recovered from Parkinsons Lake in 1981 (Penlington 1982). It is not known whether any grass carp still remain alive in the Waihi Beach reservoir.

Although the weed control potential of grass carp in lakes had been clearly demonstrated, further trials were needed to determine the efficacy of *C. idella* in the fluviatile environments of streams and drainage channels. In 1980, a 2 km long section of a drainage channel in the Hauraki Plains was screened and stocked with carp, but high mortality occurred, probably due to poor water quality. Remaining fish were not recovered but were prevented from escaping by screens on the Drainage Board's pump stations. The Mangawhero Stream, a 2 km long drain in the Aka Aka-Otaua Plains area of the Waikato River catchment proved a more successful site. In 1980, 300 grass carp were released into sections of this stream. Weed control was quickly achieved and maintained (Schipper 1983) and carp have remained there ever since.

The success of this trial led to a more ambitious plan to determine the management requirements and costs of weed control by grass carp in a larger, more realistic drainage system. The trial was to compare both the cost effectiveness and environmental effects of three different forms of weed control in drains (viz. *C. idella*, herbicides, and mechanical methods). An interdisciplinary committee, under the aegis of the Waikato Valley Authority, was set up to co-ordinate the research and a 22 km long drainage network, situated 1 km

to the west of the Mangawhero Stream in the Aka Aka-Otaua Drainage Board area, was approved for the experiments. In 1983, 2,600 grass carp were stocked into a 1 km section of this drainage catchment. In January 1984, between 1,000 and 1,600 of these fish escaped into the Waikato River through holes beneath the concrete bases of the screens (McDowall 1984). Recovery operations were unsuccessful and the trial was discontinued.

Evaluation

Ctenopharyngodon idella eliminated the exotic macrophyte *Egeria densa* in Parkinsons Lake and achieved 100% control in the Waihi Beach reservoir (Mitchell 1980). After removal of *C. idella* from Parkinsons Lake problem growths of *E. densa* did not recur because this plant does not set seed in New Zealand waters. Native species were regenerating around the margins of the lake by 1983. In the Mangawhero Stream, 100% control was also achieved and maintained for over four years until fish mortalities reduced the stocked population below levels needed for weed control.

C. idella has demonstrated a clear ability to control problem growths of aquatic macrophytes in a variety of New Zealand waters. The use of herbicides and mechanical harvesting methods in these waters would not have achieved the same level of control, nor sustained this for as long. However, this high level of weed control efficiency is the main reason for criticism of *C. idella* because the elimination of weed beds would reduce food for some waterfowl populations, may cause a decline in water quality, and could expose fish to greater predation.

Evaluations of the effects of weed removal on the water quality, fish populations and ecology of the trial lakes are reported in Mitchell (1986), Mitchell & Rowe (1979), Mitchell *et al.* (1984) and Rowe (1984) . No direct effects of grass carp on native or exotic fish populations were observed. In general, the changes in fish populations and water quality that were recorded in Parkinsons Lake were due to the consequences of weed removal on lake ecology. Removal of weed beds was followed by a decrease in density, and an increase in the growth rate, of trout *Salmo gairdnerii* Richardson. The mean size of the two forage fish species *Gobiomorphus cotidianus* McDowall and *Retropinna retropinna* (Richardson) also increased, whereas long term effects on water quality, which was largely poor, were negligible. The removal of weed beds in Parkinsons Lake resulted in changes to the ecology of the lake because the lake was small and the weed beds covered 77% of the lake (Rowe 1984).

In drainage channels, successful weed control was achieved in two areas when large fish were stocked, but failures resulted from stocking smaller fish (25-30 cm long) because bird predation reduced numbers below effective densities for weed control. Failures were also due to fish mortalities caused by poor water quality in some drains. The effects of weed control by grass carp on the aquatic fauna in drainage channels were not evaluated. This was because most channels were specifically constructed for water transport and their fishery and wildlife values existed only because of the weed problem.

Following the suspension of the large comparative trial in the Aka Aka-Otaua drainage system, Rowe & Schipper (1985) reviewed the potential impact of weed control by grass carp in New Zealand waters. They concluded that in larger lakes, where weed beds are proportionately smaller, and where fish production is based mainly on pelagic plankton rather than littoral macrophytes, impacts can be expected to be minimal. In lakes where fish production is based mainly on invertebrates associated with weed beds, weed removal will result in replacement of the weed-dwelling invertebrates with benthic grazers (e.g. gastropods) and detritovores (e.g. chironomids), both of which form important fish foods. It was concluded that the benefits of using *C. idella* for total weed control would far outweigh any environmental risks, particularly if the use of the carp were controlled by vetting of site-specific impact assessments for potential release sites.

Conclusions

Following consideration of submissions on, and public discussion of the report assessing the potential costs and benefits (economic as well as environmental) of using *C. idella* for weed control (Rowe & Schipper 1985), the Ministry of Agriculture and Fisheries recommended that government approve their release for weed control purposes. The impact assessment report had indicated that the risk of grass carp breeding in New Zealand waters was limited to the Waikato River. It concluded that, because of the specific river conditions required by this species, its reproductive success in the Waikato River would be very limited. Furthermore, the report indicated that even if *C. idella* did breed, its numbers would be too small for effective weed control, and so no significant impacts would be expected. Despite this conclusion, opposition continued. In 1986, following intervention by the Ombudsman, MAF made a commitment to the development and production of triploid, sterile grass carp for weed control. The technology for this has been recently developed in the U.S.A. (Cassani & Caton 1986, Wattendorf 1986). While the production of triploid grass carp would raise the cost of fish to users, it would also eliminate fears of *C. idella* becoming naturalised in New Zealand. It is now planned to release triploid *C. idella* for weed control in New Zealand waters.

Acknowlegement

We thank R.M. McDowall for reviewing this chapter.

Literature Cited

Brown, J.M.A. (1975) Ecology of macrophytes. Pp. 244-262 in Jolly, V.H.; Brown, J.M.A. (eds) New Zealand lakes. University of Auckland, Auckland, New Zealand.

Burnet, A.M.R. (1972) Effects of paraquat on invertebrates in a Canterbury stream, New Zealand. *New Zealand journal of marine and freshwater research* 6, 448-455.

Cassani, J.R.; Caton, W.E. (1986) The efficient production of triploid grass carp *Ctenopharyngodon idella* using hydrostatic pressure. *Aquaculture* 5, 43-50.

Chapman, V.J. (1970) A history of the lake weed infestation of the Rotorua lakes and the lakes of the Waikato hydro-electric system. *New Zealand Department of Scientific and Industrial Research information series* 78, 52 pp.

Chapman, V.J.; Coffey, B.T. (1971) Experiments with grass carp in controlling exotic macrophytes in New Zealand. *Hydrobiologia* 12, 313-323.

Cock, M.J.W. (ed.) (1985) A review of biological control of pests in the Commonwealth Caribbean and Bermuda up to 1982. *Technical communication, Commonwealth Institute of Biological Control* 9, 218 pp.

Coffey, B.T. (1970) A contribution to the autecology and control of *Lagarosiphon major*. M.Sc. thesis, University of Auckland, New Zealand. 209 pp.

Coffey, B.T. (1974) Biology of the Hydrocharitaceae in the Waikato hydro-electric lakes. Ph.D. thesis, University of Auckland, New Zealand. 146 pp.

Coffey, B.T. (1975) Macrophyte distribution in the Waikato lakes. Pp. 263-270 in Brown, J.M.A.; Jolly, V.H. (eds) New Zealand Lakes. University of Auckland, Auckland, New Zealand.

DSIR, Entomology Division, file BC 1/4.

Eady, F.C. (1972) Report on aquatic weeds in New Zealand drainage systems. *New Zealand Ministry of Agriculture and Fisheries, Field Research Section, Palmerston North. Project report* SH-33. 37 pp.

Edwards, D.J. (1973) Aquarium studies on the consumption of small animals by 0-group grass carp *Ctenopharyngodon idella* (Val.). *Journal of fish biology* 5, 599-605.

Edwards, D.J. (1974). Weed preference and growth of young grass carp in New Zealand. *New Zealand journal of marine and freshwater research* 8, 341-350.

Edwards, D.J.; Hine, P.M. (1974). Introduction, preliminary handling, and diseases of grass carp in New Zealand. *New Zealand journal of marine and freshwater research* 8, 441-454.

Edwards, D.J.; Moore, E. (1975) Control of water weeds by grass carp in a drainage ditch in New Zealand. *New Zealand journal of marine and freshwater research* 9, 283-292.

Fish, G.R. (1963) Limnological conditions and growth of trout in three lakes near Rotorua. *Proceedings of the New Zealand Ecological Society* 10, 1-7.

Fish, G.R. (1966) Some effects of the destruction of aquatic weeds in Lake Rotoiti, New Zealand. *Weed research* 6, 350-358.

Holm, L.G.; Weldon, L.W.; Blackburn, R.D. (1970) Aquatic weeds. *Pest articles and news summaries* 16, 576.

Howard-Williams, C.; Clayton, J.S.; Coffey, B.T.; Johnstone, I.M. (1987) Macrophyte invasions. Pp. 307-331 in Viner, A.B. (ed.) Inland waters of New Zealand. *DSIR Bulletin* 241.

Hughes, H.R. (1976) Research into aquatic weeds in New Zealand waterways: a review. *New Zealand Department of Scientific and Industrial Research information series* 116, 34 pp.

Johnstone, I.M.; Coffey, B.T.; Howard-Williams, C. (1985) The role of recreational boat traffic in interlake dispersal of macrophytes: New Zealand case study. *Journal of environmental management* 20, 263-279.

Marshall, J.W.; Winterbourn, M.J. (1979) An ecological study of a small New Zealand stream with particular reference to the Oligochaeta. *Hydrobiologia* 65, 199-208.

McDowall, R.M. (1979) Exotic fishes in New Zealand. Dangers of illegal releases. *New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Division information leaflet* 9, 17 pp.

McDowall, R.M. (1984) Escape of grass carp from the Aka Aka-Otaua drainage system. *New Zealand Ministry of Agriculture and Fisheries, fisheries environmental report* 44, 67 pp.

Mitchell, C.P. (1979) The Chinese grass carp *Ctenopharyngodon idella* Val., notes on the life history and induced spawning methods. Unpublished report, New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Division, Rotorua, 28 pp.

Mitchell, C.P. (1980) Control of water weeds by grass carp in two small lakes. *New Zealand journal of marine and freshwater research* 14, 381-390.

Mitchell, C.P. (1982) Grass carp – par avion. *Freshwater catch* 14, 18-19.

Mitchell, C.P. (1986) Effects of introduced grass carp on populations of two species of small native fishes in a small lake. *New Zealand journal of marine and freshwater research* 20, 219-230.

Mitchell, C.P.; Rowe, D.K. (1979) Report on grass carp trials in New Zealand. Unpublished report, New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Division, Rotorua, 55 pp.

Mitchell, C.P.; Fish, G.R.; Burnet, A.M.R. (1984) Limnological changes in a small lake stocked with grass carp. *New Zealand journal of marine and freshwater research* 18, 102-114.

Penlington, P.B. (1982) The poisoning of Parkinsons Lake. *Freshwater catch* 14, 7.

Rowe, D.K. 1984. Some effects of eutrophication and the removal of aquatic plants by grass carp *Ctenopharyngodon idella* on rainbow trout *Salmo gairdnerii* in Lake Parkinson, New Zealand. *New Zealand journal of marine and freshwater research* 18, 115-127.

Rowe, D.K.; Schipper, C.M. (1985) An assessment of the impact of grass carp (*Ctenopharyngodon idella*) in New Zealand waters. *New Zealand Ministry of Agriculture and Fisheries, fisheries environmental report* 58, 177 pp.

Schipper, C.M. (1983) Aquatic weed control and growth of grass carp in an agricultural drain. Pp. 61-68 in Proceedings of the aquatic weeds seminar. Massey University, Palmerston North, New Zealand.

Seaman, D.E.; Porterfield, W.A. (1964) Control of aquatic weeds by the snail *Marisa cornuarietis*. *Weeds* 12, 87-92.

Shireman, J.V.; Smith, C.R. (1981) Grass carp bibliography. Centre for aquatic weeds, University of Florida, U.S.A. 179 pp.

Wattendorf, R.J. (1986) Rapid identification of triploid grass carp with a coulter counter and channelyser. *Progressive fish culturist* 48, 125-132.

Waugh, G.D. (1971) Notes on the procedure for introducing and evaluating grass carp. *Freshwater Fisheries Advisory Council, report on the 27th meeting*, 40-42.

Carduus nutans L., nodding thistle (Asteraceae)

C.T. JESSEP

Pest Status

Carduus nutans L. (nodding or musk thistle), *C. acanthoides* L. (plumeless thistle), *C. tenuiflorus* Curtis (winged thistle) and *C. pycnocephalus* L. (slender-winged thistle) (Asteraceae) are the four representatives of the genus *Carduus* present in New Zealand. All can be serious weeds of pasture and pasture-related situations, but the large-flowered *C. nutans* is the most important. Native to Europe, Asia and North Africa (Clapham *et al.* 1952), *C. nutans* has become a weed in other countries, for example Canada (Mulligan & Frankton 1954), the United States of America (Dunn 1976) and Australia (Doing *et al.* 1969). Moore & Mulligan (1956) detailed evidence of hybridisation between *C. nutans* and *C. acanthoides* in Canada. New Zealand specimens in the Botany Division, DSIR, herbarium (specimen no. 356525) are also likely to be of such hybrid origin (P. Garnock-Jones pers. comm.).

C. nutans was first recorded in Otago by Kirk (1899), and by 1940 it occurred in scattered localities on the east coast of the South Island (Allan 1940). Only during the last 40 years has *C. nutans* spread to become a serious agricultural weed infesting thousands of hectares of both the North and South Islands, particularly the summer-dry areas. It is established in habitats ranging from pasture at sea-level to tussock-lands at 1,200 m. Seasonal thistle outbreaks usually follow extensive pasture depletion caused by over-grazing, drought or severe infestations by pasture insects. The principal period of seed production is during December and January but significant amounts of seed can be produced at other times. Individual plants may produce 13,000 or more seeds (Jessep in press). Natural dispersal of seed is limited (Delahunty 1962, Kelly *et al.* 1988). There are varied accounts in the literature regarding seed dormancy, e.g. (Lacefield & Gray 1970, Lee & Hamrick 1983). Jessep (in press) found that although some seed germinated immediately after release from the plant, germination rates increased after three months. Variations in germination patterns of two seed colour forms may be due to seed polymorphism (Jessep in press) and this could explain the reported differences in germination rates.

Young seedlings are poor competitors and rely heavily on bare ground for survival. Once rosettes reach ten to twelve centimetres in diameter, they can compete with other pasture species and often cause losses in pasture production. Kelly & Popay (1985) claimed that an average of 30% ground-cover by thistles resulted in losses of NZ$110/ha annually. Successful control can be achieved without damage to pasture species by the application of herbicides to small rosettes, but continuing germination of seeds in response to available soil moisture makes cost-efficient spray programmes extremely difficult. A large amount of farm resource is expended each year in controlling *C. nutans* but generally plant populations remain unacceptably high.

Background

Many insects have been recorded as being associated with *C. nutans* in New Zealand (Jessep in press, Spiller & Wise 1982). All are polyphagous and some are pests.

In 1961, Agriculture Canada commissioned CIBC to survey in central and southern Europe for phytophagous insects associated with species of the Cynareae (Zwölfer 1965). The Cana-

dian programme against *Carduus* spp. following this survey is reported by Harris & Zwölfer (1971). A receptacle weevil, *Rhinocyllus conicus* (Froelich) (Coleoptera: Curculionidae), originating from the Rhine Valley in France, was released in Canada in 1968 (Harris 1984). Subsequent releases from the Canadian population have been made in parts of the United States of America (Goeden & Ricker 1977, Kok & Surles 1975) and in New Zealand (Jessep 1975). These have generally resulted in a marked reduction in *C. nutans* seed production (Harris 1984). In Europe, *R. conicus* can complete development on thistle species of the genera *Cirsium*, *Carduus*, *Silybum* and *Onopordum*. Zwölfer & Priess (1983) found that a number of races of *R. conicus* were involved, each having a predominant or exclusive preference for a single thistle species. The biology and host specificity of the weevil have been described by Zwölfer & Harris (1984).

Another insect which attacks *Carduus* spp. is the winter-active crown weevil *Trichosirocalus* (= *Ceuthorhynchidius*) *horridus* (Panzer) (Coleoptera: Curculionidae) which was released in Canada in 1975 (Harris 1984) after host-specificity testing by Ward *et al.* (1974). The biology of this species has been recorded by Trumble & Kok (1979).

Importations, Releases and Recoveries

Rhinocyllus conicus (Froelich) (Coleoptera: Curculionidae)

In 1972, 119 adult weevils were received from the Regina Station of Agriculture Canada. Progeny from these were released at two sites in the Nelson district (260 adults at one and 26 adults at the other), and 215 adults at one site in Winchmore, central Canterbury. Two subsequent importations from the same source, totalling 3,000 adults, were used for releases near Whakatane (Jessep 1975). *R. conicus* became established at all release sites irrespective of the number released.

Trichosirocalus horridus (Panzer) (Coleoptera: Curculionidae)

In 1977 and 1978, three consignments of the weevil *T. horridus* were received from the Rome Station of the United States Department of Agriculture. Adults from two consignments perished in transit. Urgent repairs to the rearing facility at Lincoln forced the release of progeny from the third consignment before numbers were adequate for satisfactory release. They failed to become established.

Two shipments, 65 adults in total, were received from the Regina Station of Agriculture Canada, in 1982. They were of German origin. Two hundred adult weevils, the progeny of the Canadian imports, were released into a field cage over *Carduus nutans* rosettes at Winchmore in April 1984. The cage was removed one year later. *T. horridus* has since become established at this site.

Evaluation

Natural dispersal (Jessep 1981), aided by a major effort to redistribute adult weevils has resulted in *R. conicus* now being present in most *C. nutans* areas throughout New Zealand. Adults emerge in spring and oviposit on thistle buds from then until late autumn. Each female produces an average of 200 eggs, of which 70% survive to become adults (Jessep 1981). The life history of *R. conicus* has become well adapted to the seasonality of its host plant except during early spring (Jessep 1981) when weevil reproductive activity begins approximately four weeks before a significant number of *C. nutans* inflorescences become available for oviposition. Consequently, scattered early buds receive wasteful overburdens of up to 100 or more eggs. At this time of year the earlier flowering thistles *Carduus tenuiflorus* and *C. pycnocephalus*, which can often be found growing in association with *C. nutans*, receive eggs from this Upper Rhine strain of *R. conicus* (even though it prefers *C.*

nutans). Because many of these small winged thistle flower heads are physically removed by feeding larvae before either the inflorescence or the larvae mature, as few as 8% of eggs laid on this host survive to become adults. When *C. nutans* eventually produces many buds, *R. conicus* adults cease oviposition on *C. tenuiflorus* and *C. pycnocephalus* and concentrate on their preferred host.

Pre-release studies in Canterbury (Jessep in press) have confirmed that the expected seed yield of *C. nutans* is consistently related to receptacle diameter. Sampling of larvae and seeds showed that one larva per millimetre of receptacle diameter inhibited the development of all seeds and that large inflorescences could support the development of up to 45 adults. In some areas 80-100% of expected seeds from primary inflorescences were prevented from developing. Unfortunately, weevils do not exert such a pressure on the seed production from the greater numbers of subsequent, but smaller, secondary infloresences (Jessep unpublished, Popay *et al.* 1984).

In New Zealand, *R. conicus* has completed development on *Carduus nutans*, *C. acanthoides*, *C. tenuiflorus*, *C. pycnocephalus*, *Cirsium arvense* (L.) Scopoli and *Cirsium palustre* (L.) Scopoli (Asteraceae). Feeding by adults on thistle leaves is insignificant. *R. conicus* is not known to be attacked by parasitoids in New Zealand.

T. horridus is established at one site in Canterbury. Adults emerge from aestivation in late summer and oviposition occurs from then until the end of the following spring. Preliminary field investigation has shown that larval feeding can damage the central growth of rosettes and the meristem in the crown is often completely destroyed. A very long oviposition period ensures that the recurrent regrowth, which is so characteristic when *Carduus nutans* is physically damaged, is also exposed to oviposition and consequent larval damage. Adult weevils feed on thistle leaves but the damage is insignificant. In New Zealand *T. horridus* has also completed development on *Carduus tenuiflorus*, *C. pycnocephalus*, *Cirsium vulgare* (Savi) Tenore and *Cirsium palustre*.

Conclusions

R. conicus has become established throughout the range of its major host, *Carduus nutans*, from sea-level to 1,200 m. Populations are now sufficiently large that a significant proportion of seeds are prevented from developing, although many secondary inflorescences escape damage. It is not known whether *R. conicus* has yet reached its population potential. If not, then the impact on secondary inflorescences can be expected to increase.

T. horridus has not been established in New Zealand sufficiently long for its impact to be measured but present indications are that a long oviposition period will result in both the original rosette and any subsequent basal regrowth being subjected to larval feeding. Because several other thistle species are suitable hosts, available food resource should not limit population survival. A combination of the seed-inhibiting receptacle weevil (*R. conicus*) and the winter-active crown weevil (*T. horridus*) ensures that *C. nutans* will be subjected to attack by biocontrol agents throughout the year, regardless of time of germination. A significant reduction in both seed production and vigour of developing thistle rosettes by control agents should enable valuable pasture species to compete more successfully.

Acknowledgement

R.J.B. Power initiated the *C. nutans* project and arranged the import of the first consignment of *R. conicus*.

Literature Cited

Allan, H.H. (1940) A handbook of the naturalised flora of New Zealand. Government Printer, Wellington, New Zealand. 344 pp.
Clapham, A.R.; Tutin, T.G.; Warburg, E.F. (1952) Flora of the British Isles. Cambridge University Press, Cambridge, U.K. 1591 pp.

Delahunty, E. (1962) Nodding thistle. *Proceedings of the 15th New Zealand Weed Control Conference*, 24-28.

Doing, H.; Biddiscombe, E.F.; Knedlhans, S. (1969) Ecology and distribution of the *Carduus nutans* group (nodding thistles) in Australia. *Vegetatio* 10, 313-351.

Dunn, P.H. (1976) Distribution of *Carduus nutans*, *C. acanthoides*, *C. pycnocephalus* and *C. crispus* in the United States. *Weed science* 24, 518-24.

Goeden, R.D.; Ricker, D.W. (1977) Establishment of *Rhinocyllus conicus* on milk thistle in southern California. *Weed science* 25, 288-292.

Harris, P.; Zwölfer, H. (1971) *Carduus acanthoides* L., welted thistle and *C. nutans* L., nodding thistle (Compositae). *Technical communication, Commonwealth Institute of Biological Control* 4, 76-79.

Harris, P. (1984) *Carduus nutans* L., nodding thistle and *C. acanthoides* L., plumeless thistle (Compositae). Pp. 115-126 in Kelleher, J.S.; Hulme, M.A. (eds) Biological control programmes against insects and weeds in Canada 1969-1980. Commonwealth Agricultural Bureaux, Farnham Royal, U.K.

Jessep, C.T. (1975) Introduction of a weevil *Rhinocyllus conicus* for biological control of nodding thistle *Carduus nutans*. *Proceedings of the 28th New Zealand Weed and Pest Control Conference*, 205-206.

Jessep, C.T. (1981) Progress report on biological control of nodding thistle (*Carduus nutans*) in New Zealand. *Proceedings of the 5th International Symposium on Biological Control of Weeds*, 635-637.

Jessep, C.T. (in press). Aspects of the biology of nodding thistle (*Carduus nutans* L.) in Canterbury, New Zealand. *New Zealand journal of agricultural research*.

Kelly, D.; Popay, A.I. (1985) Pasture production lost to unsprayed thistles at two sites. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 115-118.

Kelly, D.; Cameron, H.; Alex, J. (1988) Wind dispersal of nodding thistle seeds and pappi. *Proceedings of the 41st New Zealand Weed and Pest Control Conference*, 207-209.

Kirk, T. (1899) The students flora of New Zealand. Government Printer, Wellington, New Zealand. 408 pp.

Kok, L.T.; Surles, W.W. (1975) Successful biocontrol of musk thistle by an introduced weevil, *Rhinocyllus conicus*. *Environmental entomology* 4, 1025-1027.

Lacefield, G.D.; Gray, E. (1970) The life cycle of nodding thistle (*Carduus nutans*) in Kentucky. *Proceedings of the 25th North Central Weed Control Conference*, 105-107.

Lee, J.M.; Hamrick, J.L. (1983) Demography of two natural populations of musk thistle (*Carduus nutans*). *Journal of ecology* 71, 923-936.

Moore, R.J.; Mulligan, G.A. (1956) Natural hybridisation between *Carduus acanthoides* and *Carduus nutans* in Ontario. *Canadian journal of botany* 34, 71-85.

Mulligan, G.A.; Frankton, C. (1954) The plumeless thistles (*Carduus* spp.) in Canada. *The Canadian field naturalist* 68, 31-36.

Popay, A.I.; Lyttle, L.A.; Edmonds, D.K.; Phung, H.T. (1984) Incidence of the nodding thistle receptacle weevil on nodding and slender winged thistles. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 28-32.

Spiller, D.M.; Wise, K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR bulletin* 231, 260 pp.

Trumble, J.T.; Kok, L.T. (1979) *Ceuthorhynchidius horridus* (Coleoptera: Curculionidae) : life cycle and development on *Carduus* thistles in Virginia. *Annals of the Entomological Society of America* 72, 563-564.

Ward, R.H.; Pienkowski, R.L.; Kok, L.T. (1974) Host specificity of the first-instar of *Ceuthorhynchidius horridus*, a weevil for the biological control of thistles. *Journal of economic entomology* 67, 735-737.

Zwölfer, H. (1965) Preliminary list of phytophagous insects attacking wild Cynareae (Compositae) species in Europe. *Technical bulletin, Commonwealth Institute of Biological Control* 6, 81-154.

Zwölfer, H.; Harris, P. (1984) Biology and host specificity of *Rhinocyllus conicus* (Froel.) (Col., Curculionidae), a successful agent for biocontrol of the thistle, *Carduus nutans* L. *Zeitschrift für angewandte Entomologie* 97, 36-62.

Zwölfer, H.; Priess, M. (1983) Host selection and oviposition behaviour in West-European ecotypes of *Rhinocyllus conicus* Froel. (Col., Curculionidae). *Zeitschrift für angewandte Entomologie* 95, 113-122.

Cirsium arvense (L.) Scopoli, Californian thistle (Asteraceae)

C.T. JESSEP

Pest Status

Cirsium arvense (L.) Scopoli (Californian, Canada or creeping thistle) is indigenous to Europe and western Asia. It is now established and widespread in other countries, particularly those within the temperate zones of both the northern and southern hemispheres (Holm *et al.* 1977). Losses caused by *C. arvense* have been reported from many countries, for example in potatoes in the United States of America (Higgins 1967), in pasture in New Zealand (Hartley & James 1979) and in wheat in Canada (Peschken *et al.* 1980). Wilson (1981) stated that toxins present in *C. arvense* plant residue and leaf leachate reduced growth of crops.

C. arvense was first recorded in New Zealand by Kirk (1878). It has spread throughout most of the country to become the most common thistle species. Intensively cropped areas, orchards, pasture-lands, tussock-country and home gardens are all suitable habitats. *C. arvense* is New Zealand's only perennial thistle. It is also the only thistle in New Zealand with rhizomatous roots. Typical patches measuring up to 5 or 6 m across can arise from one root system. Fragmentation of the root network by cultivation results in spread by vegetative propagation. The reproductive mechanisms of *C. arvense* have been described by Lloyd & Myall (1976) who found that the ability of this thistle to produce seed varies greatly.

Background

Seldom are there any aerial parts of the plant present during the late autumn and winter period and so control measures must be carried out while non-target plants are actively growing. This reduces considerably the opportunities for successful herbicide treatment without damaging useful pasture species, which are more susceptible to chemicals.

Following a survey of central and southern Europe, Zwölfer (1965a) listed 80 insect species associated with *C. arvense*. Many of these species were polyphagous and could not be considered as potential biological control agents. Five European insects have since been used against *C. arvense* in other countries. These are *Urophora cardui* (L.) (Diptera: Tephritidae) in Canada (Peschken 1984a) and the United States of America (Julien 1987), *Ceutorhynchus litura* (F.) (Coleoptera: Curculionidae) in Canada (Peschken & Beecher 1973) and the United States of America (Julien 1987), *Altica carduorum* Guérin-Méneville (Coleoptera: Chrysomelidae) in Canada 1984, Great Britain (Claridge *et al.* 1970) and the United States of America (Schaber *et al.* 1975), *Rhinocyllus conicus* (Froelich) (Coleoptera: Curculionidae) in Canada (P. Harris pers. comm. in Julien 1987) and *Lema cyanella* (L.) (Coleoptera: Chrysomelidae) in Canada (Peschken 1984a). Peschken (1984b) has described the ecology of each of these biological control agents.

Importations, Releases and Recoveries

Urophora cardui (L.) (Diptera: Tephritidae)

In September 1975, a shipment of 7,250 *U. cardui* galls from the CIBC European Station in Delémont, Switzerland, and 66 galls from the Regina Station of Agriculture Canada were received into quarantine at Lincoln. In 1976, 12 pairs of first generation adults were released

at each of ten sites and 50 pairs at another site in Canterbury. One hundred pairs were released at a single site at Kaikoura (Marlborough) in the same year (L.E. MacCarter DSIR files). In Canterbury, *U. cardui* completed one generation at one of the release sites but no other recoveries were recorded (L.E. MacCarter DSIR files). At the Kaikoura site, *U. cardui* survived, but the population remained small. Annual counts of galls on *C. arvense* stems from 1981 until 1985 showed a gradual decline in numbers (Jessep DSIR files). An extensive survey of the Kaikoura Peninsula confirmed that this population had not dispersed and that the chances of survival were slim. No adults or galls have been observed since 1985.

Ceutorhynchus litura (F.) (Coleoptera: Curculionidae)

Three consignments containing a total of 353 adult *C. litura* were received from the European Station of CIBC during 1975 and 1976. Rearing difficulties were experienced while the insects were in quarantine. A small number of first generation adults were released to a field cage at Lincoln in 1976. They failed to establish (L.E. MacCarter DSIR files).

Renewed interest in *Cirsium arvense* as a target for biological control has resulted in two consignments of *Ceutorhynchus litura* being obtained from CIBC UK at Silwood Park. One hundred and fifty four adults were received in August 1987 and 363 adults in July 1988. Following rearing in quarantine, field releases of first generation adults are planned for the seasons 1988-89 and 1989-90.

Lema cyanella (L.) (Coleoptera: Chrysomelidae)

One hundred adult *L. cyanella* were received from the Regina Station of Agriculture Canada in June 1981. After three generations in quarantine they were released into a field cage at Winchmore in central Canterbury in December 1983. Although eggs and larvae were present in the field cage later that season, *L. cyanella* failed to appear the following spring.

Altica carduorum Guérin-Méneville (Coleoptera: Chrysomelidae)

A shipment of 426 *A. carduorum* adults arrived from the European Station of CIBC in September 1977. In quarantine, diapause was interrupted and successive generations were reared in highly artifical conditions with continuous light, a temperature of 28°C and a relative humidity above 70%. *A. carduorum* adults were released into a field cage at Lincoln in 1979 but they failed to become established (L.E. MacCarter DSIR files).

Evaluation

None of the insects released in New Zealand against *Cirsium arvense* have become established. However, this does not necessarily mean that *U. cardui*, *Ceutorhynchus litura*, *A. carduorum* and *L. cyanella* are not able to adapt to the New Zealand environment. Lack of success with each of these introductions can be explained. *U. cardui* releases probably failed because insufficient numbers were released at any single site. Inadequate lighting in quarantine affected host-plant quality which severely reduced the survival rate of *C. litura*. As a result very few were released. The light, temperature and humidity regime applied to the continuous rearing of many generations of *A. carduorum* in quarantine may have been too severe. Concerns in North America regarding the likelihood of *L. cyanella* attacking native *Cirsium* species (Peschken 1984b) necessitated an extended period of artificial rearing in quarantine there. As a result, *L. cyanella* passed through ten generations under these conditions in Canada, plus another three during the quarantine and rephasing in New Zealand before eventual release. This extended rearing probably destroyed all chances of environmental adaptation and eventual establishment. The New Zealand experience with this population of *L. cyanella* is similar to the eventual result in Canada (D.P. Peschken pers. comm. 1986) where it also failed to establish.

Conclusions

C. arvense is remarkably free of phytophagous insects in New Zealand. Spiller & Wise (1982) list only five polyphagous insect species associated with this thistle. It would therefore be advisable to seek a natural balance by introducing host-specific biological control agents against this aggressive thistle. Apart from *A. carduorum* which prefers a specific number of mid-summer 'heat' days (Zwölfer 1965b) and would be better adapted to warmer areas, there is no apparent reasons why *U. cardui*, *Ceutorhynchus litura* and *L. cyanella* should not be successfully established in most areas in New Zealand where *Cirsium arvense* grows. The programme to successively introduce these species is continuing.

Acknowledgement

L.E. MacCarter was responsible for the *C. arvense* project between 1975 and 1979. The information from that period is drawn from his unpublished data.

Literature Cited

Claridge, M.F.; Blackman, R.L.; Baker, C.R.B. (1970) *Haltica carduorum* Guèrin introduced into Britain as a potential control agent for creeping thistle *Cirsium arvense* (L.) Scop. *Entomologist (London)* 103, 210-212.

Hartley, J.; James, T.K. (1979) Cost benefit of selective control of Californian thistle in pasture. *Proceedings of the 32nd New Zealand Weed and Pest Control Conference*, 245-249.

Higgins, R. (1967) Loss caused by noxious weeds in potatoes. *Down to Earth* 22, 2 & 24.

Holm, L.G.; Plucknett, D.L.; Pancho, J.V.; Herberger, J.P. (1977) The world's worst weeds. East-West Center Publication, University of Hawaii, Honolulu, U.S.A. 609 pp.

Julien, M.H. (1987) Biological control of weeds: a world catalogue of agents and their target weeds. CAB International, Wallingford, U.K. 144 pp.

Kirk, T. (1878) On the naturalized plants of Port Nicholson and the adjacent district. *Transactions and proceedings of the New Zealand Institute* 10, 362-378.

Lloyd, D.G.; Myall, A.J. (1976) Sexual dimorphism in *Cirsium arvense* (L.) Scop. *Annals of botany* 40, 116-123.

Peschken, D.P. (1984a) *Cirsium arvense* (L.) Scop., Canada thistle (Compositae). Pp. 139-146 in Kelleher, J.S.; Hulme, M.A. (eds) Biological control programmes against insects and weeds in Canada 1969-1980. Commowealth Agricultural Bureaux, Farnham Royal, U.K.

Peschken, D.P. (1984b) Host range of *Lema cyanella* (Coleoptera: Chrysomelidae), a candidate for biocontrol of Canada thistle, and of four stenophagous, foreign thistle insects in North America *Canadian entomologist* 116, 1377-1384.

Peschken, D.P.; Beecher, R.W. (1973) *Ceutorhynchus litura* (Coleoptera: Curculionidae): biology and first releases for the biological control of the weed Canada thistle (*Cirsium arvense*) in Ontario, Canada. *Canadian entomologist* 105, 1489-1494.

Peschken, D.P.; Hunter, J.H.; Thomas, A.G. (1980) Damage in dollars caused by Canada thistle in wheat in Saskatchewan *Proceedings of the Canada Thistle Symposium, Regina*, 37-43.

Schaber, B.D.; Balsbaugh, E.U.; Kantack, B.H. (1975) Biology of the fleabeetle, *Altica carduorum* (Col.: Chrysomelidae) on Canada thistle (*Cirsium arvense*) in South Dakota *Entomophaga* 20, 325-335.

Spiller, D.M.; Wise, K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR bulletin* 231, 260 pp.

Wilson, R.G. (1981) Effect of Canada thistle (*Cirsium arvense*) residue on growth of some crops. *Weed science* 29, 159-164.

Zwölfer, H. (1965a) Preliminary list of phytophagous insects attacking wild Cynareae (Compositae) species in Europe *Technical bulletin, Commonwealth Institute of Biological Control* 6, 81-154.

Zwölfer, H. (1965b) Observations on the distribution and ecology of *Altica carduorum* Guer. (Col. Chrysom.) *Technical bulletin, Commonwealth Institute of Biological Control* 5, 129-141.

Cytisus scoparius (L.) Link, broom (Fabaceae)

P. SYRETT

Pest Status

Cytisus scoparius (L.) Link is a woody shrub of European origin which has become a widespread weed in New Zealand. It grows more vigorously here than in Europe (Williams 1981) and is gazetted as a noxious plant. Broom occupies extensive areas of native grassland, riverbed and wasteland, as well as large areas of previously forested hill country.

The distribution of broom throughout New Zealand has been determined through the New Zealand Land Resource Inventory (National Water and Soil Conservation Organisation 1979) and, in the South Island alone, by Bascand & Jowett (1981). It is much more widely distributed in the South Island and has been estimated to occupy 0.92% of farmable land there (Bascand & Jowett 1981). Broom is considered to have the potential to invade extensive new areas (Dowle 1971, F. Moore 1976, L.B. Moore 1976). Its ability to grow vigorously at high altitude (there was no apparent effect of altitude on vigour up to 1,200 m on Molesworth Station, Marlborough (Stevens & Hughes 1973)) threatens much hill and high country. Stevens & Hughes (1973) noted that broom grew successfully on a wide range of soils, especially those of alluvial or colluvial origin, and on land of varied topography.

Broom is also regarded as a pest plant of agriculture and forestry in North America and India where it has been introduced (Williams 1981). In India, however, it has been used successfully as a nurse crop for commercial tree species (Chinnamani *et al.* 1965). While it is generally regarded as a weed species in New Zealand, broom is said to be of some value as a pollen source for bees (Ministry of Agriculture and Fisheries 1982), and ornamental varieties are grown in gardens to a limited extent (Grace 1984).

Conventional means of controlling broom have relied heavily on the use of the chemical 2,4,5-T, but DPX-6376 has been shown in preliminary tests to be effective (Balneaves & Cosslett 1983).

Background

The fauna of broom in New Zealand is meagre compared to that in Europe and in North America (Syrett unpublished). The few damaging species recorded include leaf-roller species (Lepidoptera: Tortricidae), and the introduced twigmining moth *Leucoptera spartifoliella* (Hübner) (Lepidoptera: Lyonetiidae). This European microlepidopteran is a specialised feeder on broom and was first recorded in New Zealand from Taupo (central North Island) in 1950 (J.S. Dugdale pers. comm.). It is widely established through most of the country and does not seem to be attacked by parasitoids. Its most effective larval parasitoid in Europe, *Tetrastichus evonymellae* (Bouché) (Hymenoptera: Aphelinidae) has not been recorded in New Zealand (Scheele & Syrett 1987).

Small numbers of aphids and mites colonise broom plants, and around the time of flowering large numbers of *Thrips obscuratus* (J.C. Crawford) (Thysanoptera: Thripidae) and an undetermined cryptophagid beetle can be found on broom (Syrett unpublished). Neither of these species causes obvious damage.

The relative absence of a phytophagous fauna on broom in New Zealand is in marked contrast to the numbers of insects found on the plant in its native Europe (Waloff 1968) and in North America where it has been introduced (Waloff 1966). This is particularly

marked in the case of the pods and seeds which support a number of species in Britain (Waloff 1968) but are apparently free from attack in New Zealand. In both Europe and North America very large populations of specialised psyllids and aphids are found on broom. The psyllids have not been found in New Zealand, nor have any specialised aphid species. Non-specialised aphids do not reach high numbers on broom (Wink *et al.* 1982), and this has been the experience in New Zealand also (Syrett unpublished).

Two insect species were selected for introduction into California for biological control of broom. These were the broom twigminer, *L. spartifoliella*, (Frick 1964) and a seed weevil, *Apion fuscirostre* (F.) (Coleoptera: Apionidae) (Andres *et al.* 1967). Both became established but were limited in their effectiveness. Accidental introductions of *L. spartifoliella* had also occurred, and the parasitoid *T. evonymellae* was found to be present (Frick 1964). *Bruchidius villosus* F. (Coleoptera: Bruchidae) (as *B. ater* (Marsham)) was accidentally introduced into the eastern United States (Bottimer 1968), and has been reported from Massachusetts, Virginia and New York State. It is not known whether it has a significant impact on seed production there.

Importations and Releases

The broom chrysomelid *Gonioctena* (= *Phytodecta*) *olivacea* (Förster) (Coleoptera: Chrysomelidae) was introduced into quarantine in December 1981 from Britain for host specificity testing on some native New Zealand species following extensive testing in the U.K. This beetle was reared successfully on several species other than broom (*Chamaecytisus palmensis* (Christ) Bisby & K. Nicholls) and species of lupin and adults fed on a wider range of leguminous plants (D.J. O'Donnell & R.L. Hill unpublished). Thus *G. olivacea* was considered unsuitable for release.

Two seed feeding species, *Apion fuscirostre* and *Bruchidius villosus*, were imported from Britain into quarantine at Lincoln in September 1985. Females of *A. fuscirostre* did not oviposit under quarantine conditions so work with this species was suspended. Host specificity tests were successfully completed with *B. villosus* showing that oviposition occurred only on *Cytisus* species (Syrett & O'Donnell 1987) and beetles were released from quarantine in November 1986 for laboratory rearing at Lincoln.

Conclusions

The programme for the biological control of broom is still in its early stages. It is hoped that field releases of *B. villosus* will be made in November 1988, and importations of further species are antipicated following the completion of host specificity tests in the U.K. by the CIBC.

Literature Cited

Andres, L.A.; Hawkes, R.B.; Rizza A. (1967) Apion seed weevil introduced for biological control of Scotch broom. *California agriculture* 21, 13.

Balneaves, J.M.; Cosslett, B.J. (1983) A preliminary look at DPX 6376 for control of mature broom. *Proceedings of the 36th New Zealand Weed and Pest Control Conference*, 41-42.

Bascand, L.D.; Jowett, G.H. (1981) Scrubweed cover of South Island agricultural and pastoral land. *New Zealand journal of experimental agriculture* 9, 307-327.

Bottimer, L.J. (1968) On the two species of *Bruchidius* (Coleoptera : Bruchidae) established in North America. *Canadian entomologist* 100, 139-145.

Chinnamani, S.; Gupte, S.C.; Rege, N.D.; Thomes P.K. (1965) Afforestation with broom as a nurse crop. *Indian forester* 91, 573-576.

Dowle, W.M. (1971) Comment : Weeds in high country. *Tussock Grasslands and Mountain Lands Institute review* 22, 15-17.

Frick, K.E. (1964) *Leucoptera spartifoliella* an introduced enemy of Scotch broom *Cytisus scoparius* in the western United States. *Journal of economic entomology* 57, 589-591.

Grace, J. (ed.) (1984) Handbook of trees and shrubs. A.H. & A.W. Reed, Wellington, New Zealand. 408 pp.

Ministry of Agriculture and Fisheries (1982) Beekeeping nectar and pollen sources, winter/spring/early summer. *Aglink* FPP 530. 4 pp.

Moore, F. (1976) Personal observations of the common broom problem in the southern part of the South Island. *Tussock Grasslands and Mountain Lands Institute review* 33, 21-23.

Moore, L.B. (1976) The changing vegetation of Molesworth Station, New Zealand, 1944-1971. *DSIR Bulletin* 217, 118 pp.

National Water and Soil Conservation Organisation (1979) Our land resources. Water and Soil Division, New Zealand Ministry of Works and Development. 78 pp.

Scheele, S.M.; Syrett, P. (1987) The broom twigminer, *Leucoptera spartifoliella* (Lepidoptera : Lyonetiidae) in New Zealand. *New Zealand entomologist* 10, 133-137.

Stevens, E.J.; Hughes, J.G. (1973) Distribution of sweet brier, broom and ragwort on Molesworth Station. *Special publication, Tussock Grasslands and Mountain Lands Institute* 9, 16 pp. & maps.

Syrett, P.; O'Donnell, D.J. (1987) A seed feeding beetle for biological control of broom. *Proceedings of the 40th New Zealand Weed and Pest Control Conference*, 19-22.

Waloff, N. (1966) Scotch broom (*Sarothamnus scoparius* (L.) Wimmer) and its insect fauna introduced into the Pacific north-west of America. *Journal of applied ecology* 3, 293-311.

Waloff, N. (1968) Studies on the insect fauna of Scotch broom *Sarothamnus scoparius* (L.) Wimmer. *Advances in ecological research* 5, 87-208.

Williams, P.A. (1981) Aspects of the ecology of broom (*Cytisus scoparius*) in Canterbury, New Zealand. *New Zealand journal of botany* 19, 31-43.

Wink, M.; Hartmann, T.; Witte L.; Rheinheimer J. (1982) Interrelationship between quinolizidine alkaloid producing legumes and infesting insects : exploitation of the alkaloid containing phloem sap of *Cytisus scoparius* by the broom aphid *Aphis cytisorum*. *Zeitschrift für Naturforschung* 37, 1081-1085.

Digitalis purpurea L., foxglove (Scrophulariaceae)

R.L. HILL

Pest Status

Digitalis purpurea L., or foxglove, is a biennial plant common in disturbed ground and in unmanaged areas throughout New Zealand. It can be recognised by its tall (1-2 m) flower stem which arises from a rosette of large, dark-green leaves and bears many white or purple bell-shaped flowers (Taylor 1981). It was first recorded in New Zealand in 1864 but by 1890 completely covered many hillsides newly cleared of bush by fire. This aroused concern that foxglove would stop the establishment of pasture on such land (Thomson 1922, Tillyard 1927) so it was declared a noxious weed in 1908. In fact, foxglove cannot survive in a competitive pasture sward and has declined in importance with progressive improvements in soil fertility and farming practice in New Zealand (Taylor 1981). It is no longer designated a noxious plant. Foxglove contains cardiac glycosides which make all parts of the plant toxic to stock and to humans, but few cases of poisoning have been recorded in New Zealand (Connor 1977).

Background

A biological control programme began in 1927 in response to the perceived threat which foxglove posed to pasture establishment.

Importations, Releases and Recoveries

On 14 December 1926, overwintering larvae of the heath fritillary butterfly, *Mellicta athalia* (Rottemburg) (Lepidoptera: Nymphalidae) were received from L. Newman, a professional butterfly collector in Kent, England. The 575 surviving larvae were caged on foxglove. Larvae fed well and the first pupa was observed on 27 January 1927. The fate of the colony beyond this date is unknown. It is unlikely that any were released (DSIR files). The heath fritillary is now an endangered species in Britain and is totally protected by the Wildlife and Countryside Act 1981. While it can be successfully reared on foxglove (Tillyard 1927), its true host-plants are probably *Plantago* spp. (Friedrich 1986) or '*Melampyrum*' sp. (Tillyard 1927).

A shipment of two further foxglove insects, *Eupithecia pulchellata* Stephens and another described as *E. pyreneata* Mabille (Lepidoptera: Geometridae) was received from England in 1928. These were kept under observation in quarantine (Miller 1929) but their fate is unknown.

Conclusions

It appears that no insects have been released in New Zealand for the control of foxglove. This is no longer a significant agricultural weed and no further introductions are envisaged.

Literature Cited

Connor, H.E. (1977) The poisonous plants in New Zealand. Government Printer, Wellington, New Zealand. 246 pp.
DSIR, Entomology Division, file BC 1/4.
Friedrich, E. (1986) Breeding butterflies and moths. A practical handbook for British and European species. Harley Books, U.K. 176 pp.
Miller, D. (1929) Noxious weeds control research. *Report of the New Zealand Department of Scientific and Industrial Research*, 18-19.
Taylor, R.L. (1981) Weeds of lawns, pasture and lucerne in New Zealand. R.L. Taylor, Nelson, New Zealand. 136 pp.
Thomson, G.M. (1922) The naturalisation of animals and plants in New Zealand. Cambridge University Press, London, U.K. 607 pp.
Tillyard, R.J. (1927) Insect control of noxious weeds. Joint scheme initiated against blackberry and other weeds. *New Zealand journal of agriculture* 34, 84-90.

Hypericum perforatum L., St John's wort (Clusiaceae)

P. SYRETT

Pest Status

St John's wort, *Hypericum perforatum* L., was first recorded in New Zealand from Great Barrier Island in 1869, and in 1896 the Dunedin Field Club catalogue recorded it as a garden escape (Jessep 1970). The plant occurs widely through New Zealand, commonly as a roadside plant. It is also found in some sown grasslands and is widespread in modified tussock grassland in eastern South Island localities (Healy 1972). Although in the North Island it is a weed of very minor importance, populations reach problem proportions in the South Island high country. St John's wort has a wide natural distribution in the northern hemisphere and occurs in a range of habitats, particularly on open, stony or disturbed ground (Hancox *et al.* 1986). It competes poorly with pasture plants so is not a problem where land is intensively managed.

St John's wort is a perennial plant producing upright stems which bear flowers in early to mid-summer. These stems senesce in autumn after seed production and then prostrate stems are produced from the crown (Campbell & Delfosse 1984). Plants possess large root reserves, and can survive heavy defoliation. Reproduction is both vegetative, when adventitious roots from prostrate stems give rise to new plants, and from seed. Numerous small seeds are produced which are readily dispersed.

Leaves and flowers of St John's wort contain hypericin which causes a photosensitization condition in sheep and cattle that have fed on the plant (Hancox *et al.* 1986). Stock losses have occurred when animals are dipped or driven through water, because hypersensitivity to water is another consequence of the condition, resulting in violent convulsions and muscle spasms.

Background

Before the introduction of biological control agents, St John's wort suffered very little from insect attack. The aphid *Macrosiphum euphorbiae* (Thomas) has been recorded from *H. perforatum* (Spiller & Wise 1982). Pasture improvement is the only effective strategy that has been used for control of St John's wort in New Zealand. While St John's wort grows well in open tussock country it competes poorly with a strong sward of pasture plants (Jessep 1970). Herbicidal control is carried out in Australia and suitable chemicals and times of application have been investigated by Campbell *et al.* (1975, 1979).

St John's wort has a wide natural distribution through Europe, North Africa and north-west Asia but has only achieved significant weed status as an immigrant species (Hancox *et al.* 1986). In California and parts of Australia in particular, St John's wort emerged as a serious rangeland weed, and in 1917 Australian workers began investigating the possibilities for biological control. Preliminary studies began in 1917 and insect introductions commenced about 1930 (Hancox 1983). The New Zealand biological control programme was initiated following the partial success of this Australian work.

Importations, Releases and Recoveries

Chrysolina hyperici (Förster) Coleoptera: Chrysomelidae)

C. hyperici was first introduced into New Zealand from Australia in 1943 (Miller 1970). The Australian population originated from England. Thirty thousand adults were released in the Awatere Valley, Marlborough, in December 1943 and three years later the population was very well established, allowing collection and redistribution to Cromwell and Arrowtown in Otago (Hancox *et al.* 1986). From 1947 to 1950 *C. hyperici* was distributed to a large number of sites throughout New Zealand (Fig. 63.1). The beetle is now established on St John's wort throughout the country.

Figure 63.1 Release sites of St John's wort beetle *Chrysolina hyperici* throughout New Zealand (1947-50).

Chrysolina quadrigemina (Suffrian) (Coleoptera: Chrysomelidae)

A second European species of *Chrysolina* (also obtained from Australia) was introduced into New Zealand in 1965 and releases totalling 100,000 beetles were made up until 1968 (Hancox *et al.* 1986) (Fig. 63.2). Initially it seemed that *C. quadrigemina* had not become established, but small numbers have been recovered in 1977 and 1984 (Fraser & Emberson 1987).

Zeuxidiplosis giardi (Kieffer) (Diptera: Cecidomyiidae)

The introduction and life cycle in New Zealand of the St John's wort gall midge have been reported by Given & Woods (1964). The gall midge was imported from Australia in 1960-61. Although releases were made at a number of South Island sites (Fig. 63.3) the gall midge has become established only in the area around Nelson (Hancox *et al.* 1986).

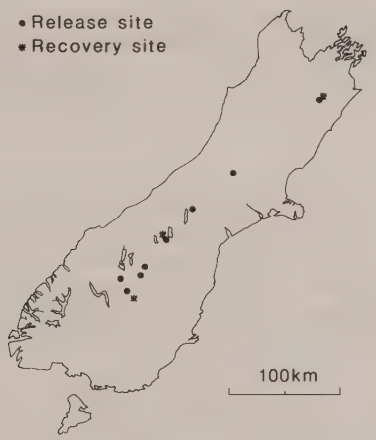


Figure 63.2 Releases and recoveries of the St John's wort beetle *Chrysolina quadrigemina*.

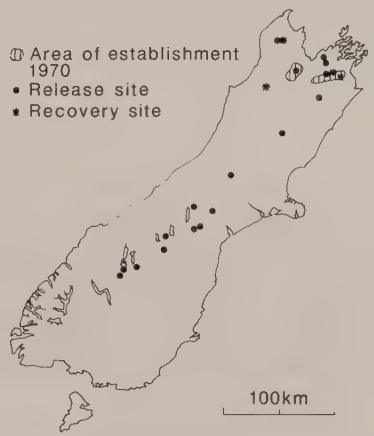


Figure 63.3 Release sites and establishment of the St John's wort gall midge *Zeuxidiplosis giardi*.

Evaluation

Of the two *Chrysolina* species, *C. hyperici* is the only one to have become successfully established and reached sufficiently high populations to have had an impact on its host plant. Initial reports described spectacular destruction of areas of St John's wort, particularly in the Awatere Valley (Miller 1970), and Moore (1976) reported that a series of photographs taken between 1947 and 1968 near where the beetles were first released in the Awatere show an initial decrease followed by later fluctuations in abundance of the weed. Although it has persisted, there has been only one marked upsurge in growth which occurred in 1959 after ground was bared by fire. In other areas the reported success of the beetle has been variable (Hancox *et al.* 1986). An insecticide trial carried out at Mt Gerald Station, Lake Tekapo, (Syrett & Hancox 1985) has shown that plots sprayed to remove the beetle contained significantly more St John's wort than unsprayed controls during the spring period when larvae were feeding actively.

Zeuxidiplosis giardi is well established and reaches high densities on plants growing in the stony river beds of the northern South Island. No attempt has been made to measure its impact on St John's wort. A torymid parasitoid (*Torymoides* sp.) has been recorded from *Z. giardi* in the Nelson area but it is not known what effect this parasitoid has on the gall midge.

Conclusions

C. hyperici has had variable success as a control agent for St John's wort in New Zealand, as it has in most other parts of the world where it has been released. In some instances it has reportedly had dramatic effects rivalling those of the highly successful control by *C. quadrigemina* in California (Huffaker & Kennett 1959), while in others its impact has apparently been negligible. A detailed quantitative evaluation was not undertaken in the years immediately following release so it is difficult now to make an informed assessment of the success of the introduction.

C. quadrigemina did not become well established in New Zealand. This experience is similar to that in parts of Canada (Williams 1985) where *C. hyperici* was found to be climatically better suited to the area than *C. quadrigemina*. The effectiveness of *Z. giardi* has varied throughout the world from being of little consequence (Australia and California) to being mainly responsible for excellent control of St John's wort in Hawaii (Hancox *et al.* 1986). Some assessment of the role of *Z. giardi* in New Zealand is required.

Literature Cited

Campbell, M.H.; Delfosse, E.D. (1984) The biology of Australian weeds 13. *Hypericum perforatum* L. *Journal of the Australian Institute of Agricultural Science* 50, 63-73.

Campbell, M.H.; Dellow, J.J.; Gilmour, A.R. (1979) Effect of time of application of herbicides on the long term control of St John's wort (*Hypericum perforatum* var. *angustifolium*). *Australian journal of experimental agriculture and animal husbandry* 19, 746-748.

Campbell, M.H.; Flemons, K.F.; Dellow, J.J. (1975) Control of St John's wort (*Hypericum perforatum* var. *angustifolium*) on non-arable land. *Australian journal of experimental agriculture and animal husbandry* 15, 812-17.

Fraser, B.; Emberson, R. (1987) Rediscovery of *Chrysolina quadrigemina* (Suffrian) (Coleoptera: Chrysomelidae) in New Zealand. *New Zealand entomologist* 9, 57-59.

Given, B.B.; Woods, G.F. (1964) Gall midge to assist in controlling St John's wort. *New Zealand journal of agriculture* 108(1), 61-63.

Hancox, N.G. (1983) Biocontrol of St John's wort (*Hypericum perforatum* L.): a review with particular reference to evaluation of the New Zealand biocontrol programme. Unpublished report. Lincoln College. 48 pp.

Hancox, N.G.; Syrett, P.; Scott, R.R. (1986) Biological control of St John's wort (*Hypericum perforatum*) in New Zealand: a review. *Plant protection quarterly* 1, 152-155.

Healy, A.J. (1972) Weedy St John's wort (*Hypericum* spp.) in New Zealand. *Proceedings of the 25th New Zealand Weed and Pest Control Conference*, 180-190.

Huffaker, C.B.; Kennett, C.E. (1959) A ten-year study of vegetational changes associated with the biological control of Klamath weed. *Journal of range management* 12, 58-82.

Jessep, C.T. (1970) St John's wort in New Zealand. *Tussock Grasslands and Mountain Lands Institute review* 20, 76-83.

Miller, D. (1970) Biological control of weeds in New Zealand 1927-48. *New Zealand Department of Scientific and Industrial Research information series* 74. 104 pp.

Moore, L.B. (1976) The changing vegetation of Molesworth Station, New Zealand. *DSIR Bulletin* 217. 118 pp.

Spiller, D.M.; Wise, K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR Bulletin* 231. 260 pp.

Syrett, P.; Hancox, N.G. (1985) Effect of an introduced beetle on St John's wort. *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 154-157.

Williams, K.S. (1985) Climatic influences on weeds and their herbivores: biological control of St John's wort in British Columbia. Pp. 127-132 in Delfosse, E.S. (ed.), *Proceedings of the Sixth International Symposium on Biological Control of Weeds*.

Rubus fruticosus L. agg., blackberry (Rosaceae)

R.L. HILL

Pest Status

The name *Rubus fruticosus* L. agg. is used in New Zealand to describe a group of at least 17 closely related, thorny *Rubus* species commonly known as blackberry (C.J. Webb pers. comm.). Blackberry is an erect, perennial shrub which can reproduce from roots, seeds, or from rooting shoot tips. It has erect or trailing stems which can be up to 8 m long. These have many curved prickles as do the midribs on the underside of the leaves (Taylor 1981). Blackberry is of European origin and was imported into New Zealand by early British colonists, presumably for fruit production. Cultivars of blackberry, including thornless varieties, have since been developed here and the berryfruit industry is expanding (Anonymous 1986).

Blackberry is an important weed in many countries (Field & Bruzzese 1985) and is widespread in many areas of New Zealand, especially where rainfall is high. Bascand & Jowett (1981) recorded it on 27,100 ha, or 0.41% of the farmable land in the South Island. Farmers there ranked it as their 13th most important weed (Bascand & Jowett 1982). It is equally abundant in the North Island but detailed information about its distribution and importance is not available.

Dense patches of blackberry can establish in places where young plants are protected from damage, and these patches can progressively displace pasture. Trailing, thorny stems around the edge of each patch can inhibit grazing by stock and can entangle grazing animals such as sheep. Blackberry outcompetes pine seedlings and can be a serious impediment to the establishment of exotic forests. It is also a major weed in national parks and reserves where it can smother native vegetation and restrict access for recreation (Timmins 1984).

Background

Blackberry can be controlled using a range of herbicides (Cornwell & Christie 1984, Field & Bruzzese 1985, Forgie *et al.* 1981, Park & Lane 1984) but regrowth from underground stems is common (Dempsey 1981).

Spiller & Wise (1982) and Miller (1970) list a number of insects which attack blackberry in New Zealand, but none of these cause significant damage. Cockayne (1912) reported that the native raspberry bud moth, *Heterocrossa* sp. (Tortricidae) was found in immense numbers attacking the young shoots of blackberry. He believed that this damage could prevent the spread of blackberry but *Heterocrossa* sp. no longer occurs in sufficient numbers to damage it severely. Blackberry bud moth, *Eutorna phaulacosma* Meyrick (Oecophoridae), is an Australian species which has become a minor pest of berryfruit crops since it was first recorded in New Zealand in 1949 (Scott 1984). It causes little significant damage to wild blackberries. The fruit are susceptible to 'red-berry disease' which is caused by the eriophyid mite *Acalitus essigi* (Hassan) (Miller 1970). It is not known how *A. essigi* arrived in New Zealand.

Blackberry is susceptible to cane spot, (*Elsinoe veneta* (Burkhart) Jenkins), and blackberry rust, (*Kuhneola uredinis* (Link) Arthur) (Dingley 1969), but neither disease causes significant damage to the plant. Miller (1970) recorded that raspberry cane wilt, *Leptosphaeria coniothyrium* (Fuckel) Saccardo, can also be damaging at times.

Blackberry species have been the subject of recent biological control measures in Chile and Hawaii (Julien 1987). The rust, *Phragmidium violaceum* (Schultz) Winter (Uredinales), was introduced into Chile from Germany in 1973. It became established, dispersed rapidly, and now causes widespread defoliation and death of young shoots. Reports claim that the area infested by the weed is decreasing (Julien 1987, Oehrens & Gonzalez 1977).

In 1979, personnel of the Australian Commonwealth Scientific and Industrial Research Organisation stationed at Montpellier, France, began an evaluation of strains of this rust on behalf of the Victoria Department of Conservation, Lands and Forests. Before this evaluation was completed however, an unknown strain of the rust was illegally imported into Australia and was released in 1984 (Bruzzese & Field 1985). The rust has spread rapidly, but its future impact remains uncertain because many strains of the rust cause only minor damage to blackberry. Australian authorities may import further strains which are known to be more virulent (Field & Bruzzese 1985). Eventually, *P. violaceum* is expected to drift eastwards from Australia to colonise blackberry in New Zealand. Plants on the west coast of the South Island have been examined regularly over the past two years but the rust has not been found (R.L. Hill & A.H. Gourlay unpublished).

The Cawthron Institute initiated a biological control programme against blackberry in 1925 because, along with gorse and ragwort, it was then regarded as the most serious weed problem facing New Zealand farmers (Thompson 1930). This programme is described in detail by Miller (1970) who lists the phytophagous insects and diseases in North America and Europe which were considered as potential control agents. Of these, eight were imported into New Zealand for evaluation.

Importations, Releases and Recoveries

Blackberry canes infested with *Pennisetia marginata* (Harris) (Lepidoptera: Sesiidae) and *Agrilus ruficollis* (F.) (Coleoptera: Buprestidae) were first received from Washington D.C., U.S.A., in December 1926. One or two adults of each species emerged but these were too few to establish viable colonies. A second consignment of *P. marginata* arrived in May 1927, and another shipment of *A. ruficollis* was received in 1931. Again, neither could be successfully reared.

According to Miller (1970), the first shipment of *Thyatira batis* L. (Lepidoptera: Thyatiridae) was received from England in December 1926, but there was an earlier shipment in November 1925 (DSIR files). Emerging moths produced larvae which were used in experiments to determine the host range of the species. Larvae fed successfully on the economically important species raspberry and loganberry, so this colony was eventually destroyed in quarantine.

A large shipment of 2,000 blackberry leaf midge, *Dasineura*(= *Perrisia*) *plicatrix* H. Loew (Diptera: Cecidomyiidae) was received from England in 1928, along with a small number of the gall midge, *Lasioptera rubi* Heeger (Diptera: Cecidomyiidae). Larvae of both species attacked raspberry. Because these small, mobile insects were difficult to contain in quarantine, the colonies were destroyed without further examination of their host range.

A shipment of *Diastrophus rubi* Hartig (Hymenoptera: Cynipidae) was sent in error in 1931 and was destroyed on arrival. Miller also records that *Mesoleuca albicillata* (L.) (Lepidoptera: Geometridae) was imported from Europe and *Diastrophus nebulosus* Osten-Sacken (Hymenoptera: Cynipidae) was imported from the U.S.A., but no further information about these species can be found. Neither species was released.

The first shipment of the buprestid beetle *Coraebus rubi* (L.) was received from England in February 1927, and by June 1931, 24 shipments had arrived. Insects were shipped inside root stocks of '*Rosa indica*' (Rosaceae) and yielded a total of 1,257 beetles. These beetles laid eggs on raspberry, loganberry and four species of the genus *Rosa* but hatching larvae

could not establish on any of these plants. Although this species developed only on blackberry, adult beetles fed heavily on the foliage of raspberry, loganberry, strawberry, apple and several fruit trees. *C. rubi* was therefore rejected as a possible control agent and the colony was destroyed (Miller 1970).

Conclusions

Eight species of insect were imported for evaluation between 1925 and 1932. All were eventually rejected because, if released, they might have damaged closely related economically important host species.

R. fruticosus is the genetic basis of a thriving export industry in berryfruit (Anonymous 1986). Although blackberry remains a serious weed in many habitats, further attempts to control it using insects could conflict with the commercial interests of berryfruit growers. It is therefore unlikely that insects will be considered again as potential biological control agents.

It is almost certain that the blackberry rust, *P. violaceum*, will colonise New Zealand from Australia. Since its illegal introduction into Australia, this rust has spread rapidly through Victoria and New South Wales (Field & Bruzzese 1985) and will eventually reach New Zealand on westerly air currents. Most commercial varieties, such as boysenberry, are of American origin and are therefore not closely related to the wild strain of blackberry which is a weed in New Zealand. The rust is host-specific to European blackberry and is unlikely to attack cultivars of American origin. However, there is a selection programme under way to incorporate the more useful agronomic characteristics of wild blackberries into commercial varieties in New Zealand (H. Hall pers. comm.). These cultivars could be susceptible to the rust. The measures used to control other diseases of blackberry on commercial plantings will also control *P. violaceum* and so the rust poses little threat to the New Zealand berryfruit industry.

If the rust established itself in New Zealand, more virulent strains which are better adapted to New Zealand conditions could then be imported from Europe to help suppress wild blackberry.

Literature Cited

Anonymous (1986) Export statistics, June 1985. *Horticulture News* 7(6), 60-71.

Bascand, L.D.; Jowett, G.H. (1981) Scrubweed cover of South Island agricultural and pastoral land. *New Zealand journal of experimental agriculture* 9, 307-327.

Bascand, L.D.; Jowett, G.H. (1982) Scrubweed cover of South Island agricultural and pastoral land 2. Plant distribution and managerial problem status. *New Zealand journal of experimental agriculture* 10, 455-492.

Bruzzese, E.; Field, R.P. (1985) Occurrence and spread of *Phragmidium violaceum* on blackberry (*Rubus fruticosus*) in Victoria, Australia. Pp. 609-612 in Delfosse, E.S. (ed.), *Proceedings of the Sixth International Symposium on the Biological Control of Weeds*. Agriculture Canada, Ottawa. 885 pp.

Cockayne, A.H. (1912) The blackberry bud moth – a promising agent for control. *New Zealand journal of agriculture* 5, 372-374.

Cornwell, M.J.; Christie, M.S. (1984) Preliminary results with DPX-T6376 for control of gorse and blackberry. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 197-199.

Dempsey, G.P. (1981) The failure of fosamine and glyphosate to give long-term control of blackberry. *Proceedings of the 34th New Zealand Weed and Pest Control Conference*, 152-155.

Dingley, J.M. (1969) Records of plant diseases in New Zealand. *DSIR bulletin* 192. 298 pp.

DSIR, Entomology Division, file BC 1/4.

Field, R.P.; Bruzzese, E. (1985) Biological control of blackberry: Resolving a conflict. Pp. 341-349 in Delfosse, E.S. (ed.) *Proceedings of the Sixth International Symposium on the Biological Control of Weeds*. Agriculture Canada, Ottawa. 885 pp.

Forgie, C.D.; Lobb, P.G.; Dryden, P.J. (1981) A comparison of a picloram/triclopyr mixture with other herbicides for blackberry control. *Proceedings of the 34th New Zealand Weed and Pest Control Conference*, 148-151.

Julien, M.H. (1987) Biological control of weeds: a world catalogue of agents and their target weeds. CAB International, Wallingford, U.K. 149 pp.

Miller, D. (1970) Biological control of weeds in New Zealand, 1927-1948. *New Zealand Department of Scientific and Industrial Research information series* 74. 104 pp.

Oehrens, E.B.; Gonzalez, S.M. (1977) Dispersion, ciclo biologico y danos causados par *Phragmidium violaceum* (Schulz) Winter como factor zarzamora *Rubus constrictus* Lef. et M. y *R. ulmifolius* Schott. en las zonas centro-sur y sur de Chile. *Agro sur* 5, 73-85.

Park, O.L.; Lane, P.M.S. (1984) Blackberry control with glyphosate. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 200-202.

Scott, R.R. (1984) Berryfruit pests. Pp. 11-24 in Scott, R.R. (ed.), New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Spiller, D.M.; Wise, K.A.J. (1982) A catalogue (1860-1960) of New Zealand insects and their host plants. *DSIR Bulletin* 231. 260 pp.

Taylor, R.L. (1981) Weeds of roadsides and waste ground in New Zealand. R.L. Taylor, Nelson, New Zealand. 176 pp.

Thompson, W.R. (1930) The biological control of insect and plant pests. A report of the organisation and progress of the work of the Farnham House Laboratory. HMSO, London, U.K. 116 pp.

Timmins, S. (1984) Weeds in national parks and reserves; summary of responses to a questionnaire. Unpublished report, New Zealand Department of Lands and Survey, Wellington. 11 pp.

Senecio jacobaea L., ragwort (Asteraceae)

P. SYRETT

Pest Status

Ragwort, *Senecio jacobaea* L., was first recorded in New Zealand in 1874, an immigrant from Europe which was probably introduced as a contaminant of seed (Syrett 1983). Much pastoral land receiving more than 800 mm rainfall per year is infested with ragwort. It is most conspicuous on dairy farms but also occurs on sheep country, in reserves and in waste places. Ragwort is typically a biennial plant but displays a range of life strategies under New Zealand conditions. Under normal grazing 80% mortality occurred among rosettes in the early stages of growth (Thompson 1985). The majority of survivors exhibited biennial behaviour, flowering in their second year, but a proportion failed to flower until the third or subsequent years. Mowing and grazing can cause plants to perenniate (Matthews & Thompson 1977) while under favourable conditions undisturbed plants may complete their life cycle in a single season (Popay 1980).

Ragwort contains pyrrolizidine alkaloids which are toxic to stock, particularly to cattle and horses (Cheeke 1984). Mortimer & White (1975) noted that ragwort was probably the major cause of plant poisoning to livestock in New Zealand. Ragwort poisoning results from recurrent sublethal doses of alkaloids which cause hepatotoxicity (Connor 1977). Death may not occur until many weeks after the animals last grazed ragwort. Livers damaged by ragwort have an increased capacity for storage of copper which can result in chronic copper poisoning. An example of this effect causing the death of two horses has been documented by Dewes & Lowe (1985). The horses were fed hay containing ragwort which resulted later in their deaths through accumulation of copper from chewing wooden rails treated with copper chrome arsenate. Although sheep are more tolerant than cattle and horses, and are even used for control of ragwort (Amor *et al.* 1983, Sharrow & Mosher 1982), they are not immune to poisoning and losses do occur. The economic impact of sublethal ragwort poisoning on stock is completely unknown (Forbes 1985).

Background

Ragwort is attacked in New Zealand by two species of Lepidoptera in particular. *Nyctemera annulata* (Boisduval) (Arctiidae) is, according to Miller (1970), both the most conspicuous feeder and the only insect to cause significant damage to ragwort. Although high larval populations occasionally defoliate ragwort very severely, parasitism at both the larval and pupal stages markedly reduce the effectiveness of this species (Syrett 1983). A second lepidopteran species, *Patagoniodes farinaria* (Turner) (Pyralidae), bores in the stem and crown of ragwort plants in the larval stage. It is thought to do some minor damage to the plant (Ireson & McQuillan 1984). Another stem borer, the dipteran *Melanagromyza senecionella* Spencer (Agromyzidae) is very common, but has no apparent impact (Syrett 1983). A leaf mining agromyzid, *Chromatomyia syngenesiae* Hardy, is also common. The aphid *Brachycaudus helichrysi* (Kaltenbach) and noctuid larvae also feed on ragwort.

Ragwort control is aided by good pasture management, as the plant competes poorly in a thick sward. Nevertheless in most situations chemical sprays are also required. Surveys carried out in Scotland indicated that over 20% of grassland infested with ragwort required spraying annually merely to maintain the frequency of infestation at its current level (Forbes

1985). Matthews & Thompson (1977) suggested that in New Zealand large multicrown plants can be treated by spot application of picloram granules or, if left to complete their life cycles, will die naturally in an ungrazed situation. High rates of herbicide application on infested pasture cause severe clover damage, but if multicrown plants are dealt with separately, smaller rosettes may be adequately controlled by low rates of 2,4-D. Thompson & Saunders (1984) have shown that 2,4-D is superior to MCPA for control. Autumn applications are less effective than spring (Forbes 1985, Thompson 1980), but cause less clover damage. Another disadvantage of spring spraying is that after treatment with the herbicides 2,4-D and MCPA, ragwort becomes more palatable to stock which must be excluded from sprayed areas (Forbes 1985). Successful control of flowering plants has been achieved by use of glyphosate and a rope wick applicator (Makepeace & Thompson 1982).

Importations, Releases and Recoveries

Tyria jacobaeae (L.) (Lepidoptera: Arctiidae)

Consignments containing pupae of the cinnabar moth, *Tyria jacobaeae* (L.) (Lepidoptera: Arctiidae), were imported from England between 1926 and 1931 (Miller 1970). The cinnabar moth was first released in the field in 1929, and between 1929 and 1932 nearly 3.5 million eggs were distributed on ragwort throughout the country. Main liberation areas were Nelson, Auckland, Taranaki and Southland. Initial establishment was very good in some areas but populations failed to be maintained for more than two or three years. In 1941 it was reported in particularly large numbers at Horahora along the Waikato river, and a few years later there were records from the Wairarapa (Syrett 1983). To date the moth persists in abundance only through the southern North Island from Wellington to Pahiatua and the Manawatu (Fig. 65.1). It appears to have extended its range both northwards and southwards from the

Table 65.1 Redistribution of cinnabar moth, *Tyria jacobaeae* (L.)

Date	Site	Number of larvae released	Recoveries
9 September 1974	Ngakawau, Buller	?	not established
17 January 1979	Opouri Valley, Marlborough	?	not established
	Rotomanu, N. Westland	?	not established
	Lake Sumner, Hurunui	?	not established
23 October 1979	Rotomanu, N. Westland	?	not established
27 January 1982	Staveley, Canterbury	300	not established
15 February 1982	Karamea, Buller	300	adults in January, 1983
7 December 1983	Upper Takaka, Golden Bay	2,000	larvae
20 December 1983	Whataroa, Westland	2,200	larvae
10 January 1984	Karamea, Buller	2,000	larvae and adults, increasing
17 January 1984	Otautau, Southland	5,000	larvae and adults, increasing January, 1986
January 1985	Nile River, N. Westland	1,000	?
	Carters Beach, N. Westland	1,000	larvae and adults, increasing
	German Gully, N. Westland	1,000	?
	Waimanaroa, N. Westland	1,000	adults
19 January 1985	Pipiwai, Northland	5,000	larvae and adults but not found in 1985-86
December 1985	Inangahua, N. Westland	?	larvae and adults increasing
9 December 1985	Hanmer, Amuri	1,000	larvae

? = not known

Figure 65.1. Present distribution of cinnabar moth, *Tyria jacobaeae* (L.) in New Zealand. The shaded area represents the area of establishment following original releases.
○ = Release sites, ◑ = Recovered, ● = Established.

Wairarapa area where it has persisted since the early liberations.

From 1982 until the present a number of re-releases of material collected from the Wairarapa have been made at sites throughout the country (Table 65.1). The success of these operations has been mixed and it is too early to say whether long-term establishment has occurred.

Botanophila (=*Pegohylemyia*) *seneciella* (Meade) and *B.* (=*P.*) *jacobaeae* (Hardy) (Diptera: Anthomyiidae)

Fourteen consignments of ragwort seedfly puparia were imported from England between 1928 and 1939 and emerging adults were released between 1936 and 1940. Details of importations and releases are described by Miller (1970). Although both species must have been liberated (Holloway 1983) recent recoveries have been of *B. jacobaeae* only. The current distribution of the ragwort seedfly is shown in Fig. 65.2. Several attempts have been made to transfer the seedfly to other areas (Table 65.2) but so far these appear to have been unsuccessful (Syrett *et al.* 1984).

Figure 65.2. Present distribution of ragwort seedfly, *Botanophila jacobaeae* (Hardy) in New Zealand.

Table 65.2 Redistribution of ragwort seedfly, *Botanophila jacobaeae* (Hardy)

Date	Site	Number of pupae released	Recoveries
3 November 1975	Hapuku, Kaikoura	200	–
25 May 1982	Paturau, Golden Bay	500	–
10 January 1983	Cobb reservoir, Golden Bay	515	–
5 December 1984	Tadmor Valley, Nelson	1,630	–

Longitarsus jacobaeae (Waterhouse) (Coleoptera: Chrysomelidae)

The ragwort flea beetle, *L. jacobaeae* (Waterhouse) (Coleoptera: Chrysomelidae), was introduced into New Zealand from Oregon in 1981 and first released in the field in April 1983 (Syrett *et al.* 1984). The Oregon beetles originated from an Italian strain imported into the United States from Europe in the 1960s. Additional host specificity studies were carried out prior to release to investigate the susceptibility of a selection of related *Senecio* species native to New Zealand (Syrett 1985).

Field releases to date are listed in Table 65.3. The first releases on the South Island were disappointing but results from releases made in 1985 in the northern part of the North Island have been very encouraging so far. Populations have increased markedly in the second and third seasons at most sites. Those sites which have not shown substantial increases in beetle populations have been conspicuous for extremely low ragwort populations. Beetles released into cages at Lincoln, Canterbury, which had been planted with ragwort rosettes increased in numbers by five times and three times over two successive years (Syrett 1986). Significant mortality of ragwort plants occurred for larval densities averaging about 40 per plant.

Table 65.3 Field releases of the ragwort flea beetle, *Longitarsus jacobaeae* (Waterhouse)

Date	Site	Number of adults released	Recoveries
24 April 1983	Inchbonnie, N. Westland	300	1984 & 1985 declining
22 April 1983	Canvastown, Marlborough	230	?
19 March 1984	Ngatira, Mamaku	300	1985 eggs & larvae
21 March 1984	Kaiparoro, Wairarapa	300	1985 adults
11 April 1984	Cobb reservoir, Golden Bay	300	1985 declining
21 March 1985	Colac Bay, Southland	500	?
	Riverton, Southland	500	?
1 April 1985	Kaihu valley, Hobson	500	1985, 1986 increasing
	Gammons Rd, Kaikohe	500	1985, 1986 increasing
	Motatau, Kawakawa	500	1985, 1986
2 April 1985	Titoki, Whangarei	500	1985, 1986 increasing
19 April 1985	Upper Takaka, Golden Bay	500	1986 adults
7 May 1985	Ngaroma, Otorohanga	500	1986 increasing
8 May 1985	Whitford, S. Auckland	500	1986 larvae, adults
10 May 1985	Burr Rd, Whakatane	500	1985, 1986 increasing
14 May 1985	Kapowai Rd, Coromandel	500	1985, 1986 increasing
15 May 1985	Mangakino, Taupo	500	1985, 1986
25 May 1985	Charleston, Westland	500	1986 larvae, adults
29 January 1986	Wrights Rd, Rodney	500	1986 larva
30 January 1986	Te Pahu Rd, Raglan	500	?
18 March 1986	Atiamuri, Rotorua	500	1986 larvae
19 March 1986	Hangitiki, Waitomo	500	1986 larvae
25 March 1986	Rotokauri, Hamilton	500	?
	Te Miro, Waikato	500	1986 larvae
7 April 1986	Inangahua, N. Westland	1,500	?
	Hanmer, Amuri	1,500	1986 larva
21 April 1986	St Arnaud, Nelson Lakes	500	?

? = not known

Further releases are being made throughout the country and there are plans to undertake an assessment of the impact of the beetle on ragwort in the field.

Evaluation

No quantitative evidence is available as to the effect of cinnabar moth on ragwort in New Zealand. Severe defoliation has been reported in some years over some areas but the longer term effect on ragwort populations is not known. Parasitism and bird predation account for some mortality (Miller 1970) but this is not thought to be an important factor compared to losses occurring through unfavourable climatic conditions.

The impact of ragwort seedfly on its host plant has been shown to be negligible (Dymock 1987). Only 10-20% of seedheads were infested at two field sites and up to 200 seedheads per square metre escaped attack. No further efforts are currently being made to redistribute this species.

Acknowledgements

Records from the following are acknowledged with thanks: P.L. Ayson, R.M. Broadhurst, J. Craw, J.J. Dymock, E.J. Eden, H.M. Harman, C.T. Jessep, B. Menzies, R.S. Morgan, S.M. Scheele, C.J. Winks.

Literature Cited

Amor, R.L.; Lane, D.W.; Jackson, K.W. (1983) Observation on the influence of grazing by sheep or cattle on the density and cover of ragwort. *Australian weeds* 2, 85-94.

Cheeke, P.R. (1984) Comparative toxicity and metabolism of pyrrolizidine alkaloids in ruminants and non ruminant herbivores. *Canadian journal of animal science* 64(suppl.), 201-202.

Connor, H.E. (1977) The poisonous plants in New Zealand. Government Printer, Wellington, New Zealand. 247 pp.

Dewes, H.F.; Lowe, M.D. (1985) Haemolytic crisis associated with ragwort poisoning and rail chewing in two thoroughbred fillies. *New Zealand veterinary journal* 33, 159-160.

Dymock, J.J. (1987) Population changes of the seedfly *Pegohylemyia jacobaeae* (Diptera: Anthomyiidae) introduced for biological control of ragwort. *New Zealand journal of zoology* 14, 337-342.

Forbes, J.C. (1985) The impact and control of ragwort (*Senecio jacobaea* and *S. aquaticus*) in grassland. Pp. 147-154 in Brockman, J.S. (ed.) Weeds, pests and diseases of grassland and herbage legumes. British Crop Protection Council Monograph 29.

Holloway, B.A. (1983) Species of ragwort seedflies imported into New Zealand (Diptera: Anthomyiidae). *New Zealand journal of agricultural research* 26, 245-249.

Ireson, J.E.; McQuillan, P.B. (1984) Observations on the biology and behaviour of *Homoeosoma farinaria* Turner (Lepidoptera: Pyralidae) on *Senecio jacobaea* L. in Tasmania. *Journal of the Australian Entomological Society* 23, 285-292.

Makepeace, W.; Thompson, A. (1982) Ragwort control using a rope-wick applicator. *Proceedings of the 35th New Zealand Weed and Pest Control Conference*, 256-260.

Matthews, L.J.; Thompson, A. (1977) Ragwort control through seeding then spraying. *Proceedings of the Ruakura Farmers Conference* 29, 6-7.

Miller, D. (1970) Biological control of weeds in New Zealand 1927-48. *Department of Scientific and Industrial Research information series* 74, 104 pp.

Mortimer, P.H.; White, E.P. (1975) Toxicity of some composite (*Senecio*) weeds. *Proceedings of the New Zealand Weed Conference* 28, 88-91.

Popay, A.I. (1980) Biology of ragwort. *Protect* 1(1), 7-8.

Sharrow, S.H.; Mosher, W.D. (1982) Sheep as a biological control agent for tansy ragwort. *Journal of range management* 35, 480-482.

Syrett, P. (1983) Biological control of ragwort in New Zealand: a review. *Australian weeds* 2, 96-101.

Syrett, P. (1985) Host specificity of the ragwort flea beetle *Longitarsus jacobaeae* Waterhouse (Coleoptera: Chrysomelidae). *New Zealand journal of zoology* 12, 335-340.

Syrett, P. (1986) Preliminary observations on the ragwort flea beetle in New Zealand. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 110-113.

Syrett, P.; Scheele, S.M.; Philip, B.A. (1984) Renewed activities in biological control of ragwort. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 37-41.

Thompson, A. (1980) Ragwort population and control studies. *Proceedings of the 33rd New Zealand Weed and Pest Control Conference*, 59-62.

Thompson, A. (1985) Population studies on ragwort (*Senecio jacobaea*). *Proceedings of the 38th New Zealand Weed and Pest Control Conference*, 122-124.

Thompson, A.; Saunders, A. (1984) A comparison of 2,4-D and MCPA alone and in combination, for the control of ragwort. *Proceedings of the 37th New Zealand Weed and Pest Control Conference*, 33-36.

Ulex europaeus L., gorse (Fabaceae)

R.L. HILL and A.H. GOURLAY

Pest Status

Gorse, *Ulex europaeus* L., is a spiny shrub which can form impenetrable thickets over 2 m tall. It was brought to New Zealand from Europe over 150 years ago, for use as a hedge plant or as stock food, and successfully colonised much of the land which was cleared of forest to establish pasture. Despite intense efforts to control it since then, gorse is still found on more than 900,000 ha, of which 166,000 ha has more than 40% gorse cover (Blaschke *et al.* 1981, Sandrey 1985). Gorse occupies 3.6% of the farmable land in the South Island and farmers there perceive it as their second worst weed (Bascand & Jowett 1981, 1982). Not only does gorse invade pasture and occupy potential grazing land, but its strong competitive ability inhibits the establishment and maintenance of exotic forests (Zabkiewicz & Balneaves 1984). Gorse seed can remain viable for at least 30 years in the soil, so that land can become reinfested many years after gorse plants have been removed. Gorse therefore remains a constant threat to farmers especially on land which cannot be cultivated.

The costs of gorse in New Zealand are reviewed by Sandrey (1985) and Hill (1986) and summarised by Hill & Sandrey (1986). Sandrey (1985) estimated the direct cost of gorse to farming and forestry to be at least NZ$17.8 million annually. Additional indirect costs such as lost production from gorse-infested land probably exceed this figure (Hill & Sandrey 1986). Monsanto (1984) have estimated the total cost of gorse to the New Zealand economy at NZ$150 million each year.

MacCarter & Gaynor (1980) discuss the feasibility of biological control of gorse and Gaynor & MacCarter (1981) provide a world bibliography of gorse research.

Background

Although gorse is a serious weed in many situations, its control is not universally favoured. Even when the first attempt to control gorse began in 1927, the only control agents considered were seed-feeding insects because gorse was valued as a hedge-plant (Miller 1970). When biological control of gorse was proposed again in 1977, this was no longer regarded as a serious impediment because other fencing methods had largely superseded gorse hedges. However, other beneficial attributes of gorse have been proposed. Gorse is regarded as an important pollen source for bees in early spring, ensuring strong hives for honey production in the summer. Native vegetation appears to regenerate quickly under gorse in parts of the country. Some conservationists therefore value gorse as a nurse crop. Researchers are also interested in developing gorse as a fodder crop for goat production. These and other issues are discussed by Hill (1986). Conflicts of interest therefore exist between those who benefit from gorse and those who would like to see it controlled. Over the past four years there has been a systematic attempt to quantify these costs and benefits of gorse to the New Zealand environment and economy (Hill & Sandrey 1986, Sandrey 1985, 1987), and to reach a consensus on these issues. This process resulted recently in a comprehensive environmental impact assessment of the proposed project which was published late in 1987 (Hill 1987). Following public submissions, independent evaluation of this assessment led to a decision in March 1988 to proceed with the biological control programme (Hill in press). In the meantime, some possible control agents have been evaluated.

The insect fauna of gorse in Europe is well known. At the request of R.J. Tillyard of the Cawthron Institute, early studies of gorse insects were carried out in England at the Rothamsted Experimental Station and at the Imperial Bureau of Entomology in the U.K. (Chater 1931, Davies 1928). Detailed surveys have since been carried out in France (Zwölfer 1962, 1963, 1965) Spain (O'Donnell 1986) and southern England (Hill 1982). Of the 94 insect species known to attack gorse in Europe, 16 are sufficiently host-specific to be evaluated as possible control agents (Table 66.1) and this research is under way. Safety-tests of the most promising of these, *Tetranychus lintearius* Dufour (Acari: Tetranychidae), have shown that it is suitable for release in New Zealand (Hill 1987, Hill & D.J O'Donnell unpublished).

Table 66.1 European insects which are potential control agents for gorse, *Ulex europaeus* L.

Species	Family	Feeding site
ACARI		
Tetranychus lintearius Dufour	Tetranychidae	on foliage
COLEOPTERA		
Apion scutellare Kirby	Apionidae	in shoots
DIPTERA		
Asphondylia ulicis (Verrall)	Cecidomyiidae	in buds
Dasineura sp.	Cecidomyiidae	in shoots
HEMIPTERA		
Dictyonota strichnocera Fieber	Tingidae	on foliage
LEPIDOPTERA		
Agonopterix nervosa (Haworth)	Oecophoridae	in flowers
Agonopterix ulicetella (Stainton)	Oecophoridae	on foliage
Anarsia spartiella (Schrank)	Gelechiidae	in flowers
Coleophora albicosta (Haworth)	Coleophoridae	in pods
Cydia internana (Guenée)	Tortricidae	in pods
Cydia succedana (Denis & Schiffermüller)	Tortricidae	in pods
Phyllonorycter ulicicolella (Stainton)	Gracillariidae	in shoots
Scythris gallicella (de Joannis)	Scythrididae	on foliage
Scythris grandipennis (Haworth)	Scythrididae	on foliage
THYSANOPTERA		
Odontothrips ulicis (Haliday)	Thripidae	in flowers
Sericothrips staphylinus Haliday	Thripidae	on foliage

The insect fauna of gorse already present in New Zealand was examined by MacCarter & Gaynor (1980). *Icerya purchasi* Maskell (Homoptera: Margarodidae) and *Oemona hirta* (F.) (Coleoptera: Cerambycidae) can sometimes damage gorse. A stem-borer, *Anisoplaca ptyoptera* Meyrick (Lepidoptera: Gelechiidae) can cause considerable dieback in otherwise healthy plants, but attack is sporadic. It is an indigenous species and its true hosts in New Zealand are species of the leguminous tribe Carmichaeliae, which does not occur outside New Zealand (Butler 1979). For this reason, *A. ptyoptera* may have value as a control agent in other countries.

Recently, we have recorded two other species feeding on gorse in New Zealand. Stem deformities commonly found on mature gorse stems in Westland are formed by the stem and bulb nematode, *Ditylenchus dipsaci* (Kühn) Lilipjev (J. Marshall, W. Wouts pers. comm.). This association has been found only in Westland. An eriophyid mite which is

indistinguishable from the European species *Aceria genistae* (Nalepa) (D.C.M. Manson pers. comm.) has also been found attacking gorse. It appears to be widely distributed in the South Island and often causes slight growth abnormalities in growing shoots. The impact of damage caused by either species on the vigour of gorse is unknown.

Importations, Releases and Recoveries

Apion ulicis Förster (Coleoptera: Apionidae)

The first attempt to control gorse biologically in New Zealand began in 1927 with the importation of gorse seed weevil, *Apion ulicis*. Between 1927 and 1931, 31 shipments totalling 320,280 weevils were sent from the Imperial Bureau of Entomology, Farnham Royal, England. Of these, 84,768 were alive on arrival, and these were evaluated in quarantine. Host range tests carried out in both England and New Zealand showed that *A. ulicis* could not attack any other plant (Davies 1928, Miller 1970). The first releases of New Zealand-bred weevils were made in February 1931 in Nelson and Alexandra. At this point it was decided to release directly adult weevils which had been collected from gorse pods in the laboratory in England. Over 38,000 such weevils were imported and released in the following year. A total of 235,000 adult weevils was distributed throughout New Zealand between 1931 and 1946 (Miller 1947).

The weevil established readily and soon as many as 99% of pods were attacked each spring (Miller 1947). Miller (1970) claimed gorse seed weevil to be one of the commonest insects in New Zealand.

Agonopterix ulicetella Stainton (Lepidoptera: Oecophoridae)

The host-range of *Agonopterix ulicetella* Stainton (Lepidoptera: Oecophoridae) was studied in England between 1978 and 1982. Three shipments of moths were later despatched from CIBC at Silwood Park for further evaluation under quarantine conditions in New Zealand in 1982 and 1983. In laboratory tests, five of the 63 plant species tested appeared to be possible alternative hosts for this moth. All were closely related to gorse. Four were not of any environmental or economic importance in New Zealand but one of the species was tagasaste, *Chamaecytisus palmensis* (Christ) Bisby & K. Nicholls, which may become an important forage shrub in New Zealand in the future. There are no plans to release *A. ulicetella* in New Zealand until field studies in England show that it cannot colonise tagasaste under natural conditions (Hill, Gourlay & O'Donnell unpublished).

On the completion of experiments, colonies of *A. ulicetella* were sent to Chile and Hawaii for similar evaluation there.

Dictyonota strichnocera Fieber (Hemiptera: Tingidae)

This species was also studied in England from 1978 to 1982 and in New Zealand from 1982 to 1984. Its life history is described by Brown (1981). *D. strichnocera* also developed on tagasaste in the laboratory and cannot be released in New Zealand without further study (Hill, Gourlay, O'Donnell & C. Speed unpublished).

Tetranychus lintearius Dufour (Acari: Tetranychidae)

In laboratory host-range tests, populations of *T. lintearius* developed only on gorse and the very closely related species *Genista hispanica* L. and *G. tinctoria* L., while some development also occurred on *Phaseolus vulgaris* L. (Fabaceae) (Hill 1987). Of these four species, gorse is the only known host in the field in Europe. Detailed experiments showed that *P. vulgaris* could not support the development of *T. lintearius* populations in the field (Hill 1987,

O'Donnell unpublished). Cross-breeding experiments showed that *T. lintearius* was reproductively isolated from the important pest *T. urticae* Koch (Hill 1987, Hill & O'Donnell unpublished). On the basis of these results, *T. lintearius* was approved as a suitable control agent for gorse.

In August 1988, 200 adult female *T. lintearius* were imported from CIBC, U.K. The founders of this population originated from Porthtowan, Cornwall (Hill unpublished). Following a period of quarantine for the exclusion of predators and diseases, this mite is now being reared for widespread release from November 1988.

Evaluation

Only one species has been released to attack gorse in New Zealand to date. Miller (1947) initially claimed that the high level of attack on green gorse pods by *Apion ulicis* would destroy most gorse seed and ultimately lead to gorse control because very little seed is produced at other times of the year. This has not proven to be the case. Recent studies confirm Miller's observation that between 85 and 95% of green pods formed in the spring can be attacked by the weevil. Unfortunately, Miller's claim that little seed is formed at other times of the year is false. In some areas, most seed forms not in spring but in autumn, when the weevil is not reproductively active. This lack of synchrony is the reason why *A. ulicis* has not controlled gorse in New Zealand (Hill, Gourlay & L. Martin unpublished).

The true role which *A. ulicis* has played in the population dynamics of gorse since 1931 is very difficult to determine. A fair evaluation requires better knowledge of gorse seed production, dispersal and survival, and a better understanding of gorse population dynamics. Research continues in this area. It seems certain that the introduction of better adapted strains of this weevil or further species of seed-feeding insects would reduce the amount of seed produced by gorse.

Conclusions

Although *Apion ulicis* destroys much gorse seed each year, this has not resulted in adequate gorse control. A comprehensive environmental impact assesment has been completed which has shown that the costs of gorse to the New Zealand economy and environment outweigh its benefits. A renewed biological control programme has begun and the gorse spider mite, *T. lintearius*, has been introduced. Research into the suitability of approximately 15 other species as potential control agents for gorse continues and some of these will be introduced in future years.

Literature Cited

Bascand, L.D.; Jowett, G.H. (1981) Scrubweed cover of South Island agricultural and pastoral land. *New Zealand journal of experimental agriculture* 9, 307-492.

Bascand, L.D.; Jowett, G.H. (1982) Scrubweed cover of South Island agricultural and pastoral land. 2. Plant distribution and managerial problem status. *New Zealand journal of experimental agriculture* 10, 445-492.

Blaschke, P.M.; Hunter, G.G.; Eyles, G.O.; van Berkel, P.R. (1981) Analysis of New Zealand's vegetation cover using land resource inventory data. *New Zealand journal of ecology* 4, 1-19.

Brown, V.C. (1981) Studies on the biology and ecology of the gorse lace bug *Dictyonota strichnocera* Fieber (Heteroptera: Tingidae). M.Sc. thesis, Imperial College, University of London, U.K. 78 pp.

Butler, J.H.B. (1979) Control of gorse by *Anisoplaca ptyoptera*. *Proceedings of the 32nd New Zealand Weed and Pest Control Conference*, 307-308.

Chater, E.H. (1931) A contribution to the study of the natural control of gorse. *Bulletin of entomological research* 22, 225-235.

Davies, W.M. (1928) The bionomics of *Apion ulicis* Forst. (gorse weevil), with special reference to its role in the control of *Ulex europaeus* in New Zealand. *Annals of applied biology* 15, 263-286.

Gaynor, D.L.; MacCarter, L.E. (1981) Biology, ecology and control of gorse (*Ulex europaeus* L.) a bibliography. *New Zealand journal of agricultural research* 24, 123-139.

Hill, R.L. (1982) The phytophagous fauna of gorse (*Ulex europaeus* L.) and host plant quality. Ph.D. thesis, Imperial College, University of London, U.K. 268 pp.

Hill R.L. (1986) Biological control of gorse: implications for the natural environment and primary production. *DSIR Entomology Division report* 5, 130 pp.

Hill, R.L. (in press) Decision-making in the biological control programme against gorse in New Zealand. *Proceedings of the VII International Symposium on the Biological Control of Weeds, Rome, Italy, March 1988.*

Hill, R.L.; Sandrey, R.A. (1986) The costs and benefits of gorse. *Proceedings of the 39th New Zealand Weed and Pest Control Conference*, 70-73.

MacCarter, L.E.; Gaynor, D.L. (1980) Gorse: a subject for biological control in New Zealand. *New Zealand journal of experimental agriculture* 8, 321-330.

Miller, D. (1947) Control of gorse by seed weevil. *New Zealand journal of agriculture* 75, 341-344.

Miller, D. (1970) Biological control of weeds in New Zealand 1927-1948. *New Zealand Department of Scientific and Industrial Research information series* 74, 104 pp.

Monsanto (N.Z.) Ltd (1984) The estimated costs of weeds to the agricultural sector of the New Zealand economy. Discussion paper, 15 pp.

O'Donnell, D.J. (1986) A survey of the natural enemies of gorse (*Ulex* sp.) in northern Spain and Portugal. Unpublished report, Commonwealth Institute of Biological Control, 22 pp.

Sandrey, R.A. (1985) Biological control of gorse: an ex-ante evaluation. *Agricultural Economics Research Unit, Lincoln College, research report* 172, 96 p.

Sandrey, R.A. (1987) Gorse and goats: considerations for the biological control of gorse. *Agricultural Economics Research Unit, Lincoln College, discussion paper* 107, 18 pp.

Zabkiewicz, J.A.; Balneaves,J.M. (1984) Gorse control in New Zealand forests – the biology and the benefits. *Aspects of applied biology* 5, 255-264.

Zwölfer, H. (1962) *Ulex europaeus* project, European investigations for New Zealand, report no. 1. Commonwealth Institute of Biological Control, 14 pp.

Zwölfer, H. (1963) *Ulex europaeus* project, European investigations for New Zealand, report no. 2. Commonwealth Institute of Biological Control, 30 pp.

Zwölfer, H. (1965) *Ulex europaeus* project, European investigations for New Zealand, report no. 3. Commonwealth Institute of Biological Control, 4 pp.

PART 6.

Nuisance Pests

Four very diverse programmes are described in this section. The target in each case is a group of insects which harass or inconvenience humans in New Zealand. Native black flies, *Austrosimulium* spp., (known in New Zealand as 'sandflies'), have a painful bite and can be very abundant at times, especially on the west coast of the South Island. Chapter 67 describes an early attempt to introduce predatory dragonflies from Australia to attack sandfly larvae. As well as causing a nuisance, some blow flies (Calliphoridae) are responsible for 'flystrike' in sheep (the infestation of wool and skin lesions) which can lead to significant stock losses. Parasitoids which attack the larvae and pupae of calliphorid flies were imported and released in New Zealand as early as 1919. This work is described in Chapter 68. The muscid flies include the house fly, a common nuisance around human habitations, and several species of biting flies which bother farm animals. During the 1960s, a worldwide biological control programme was carried out against muscid flies. In the course of this project, four parasitoid species were introduced into New Zealand to attack muscid pupae. This programme is reviewed in Chapter 69. Vespid wasps have been a problem in most parts of New Zealand for many years, and the recent establishment of the common wasp has heightened concern. Wasps sting both humans and stock and sometimes occur in sufficient numbers to restrict human activities in some areas. Recent studies suggest that wasps also affect ecological relationships in native forests. A pioneering biological control programme against vespid wasps is described in Chapter 70. Although in its early stages, this programme is being watched with interest by those in other countries with similar wasp problems.

Austrosimulium australense (Schiner), New Zealand black fly and *Austrosimulium ungulatum* Tonnoir, West Coast black fly (Diptera: Simuliidae)

T.K. CROSBY

Pest Status

In New Zealand black flies are known as 'sandflies', and most people have first-hand experience of being bitten by them. The two main man biting species present are *Austrosimulium australense* (Schiner) and *A. ungulatum* Tonnoir. The magnitude of biting rates by females ranks them with other important black fly pest species in the world (Crosskey 1981). Biting rates of over 1,000 per hour are not uncommon (unpublished observations). All stages of these species can be found at all times of the year, although they are more common in the warmer months. It is not known what native animals the females of these species usually feed on apart from Fiordland crested penguins (Crosby 1976), but my unpublished observations suggest they are not host specific.

A. australense occurs throughout New Zealand except the Canterbury Plains, North Otago and Fiordland (Dumbleton 1973). It is an avid biting species in the North Island. Larvae are usually found on vegetation in open, steadily flowing streams ranging in size from trickles to rivers. *A. ungulatum* occurs in the South Island and Stewart Island where it is the principal pest species. Larvae are usually found on stones in fast flowing small streams in heavily forested areas, and are never found in high numbers in spite of the abundance of biting females.

No species has been proven to transmit viruses or diseases to man. Austin (1967) demonstrated that *A. ungulatum* could be a mechanical vector of an arbovirus (Whataroa M78). *A. ungulatum* proved to be the main vector of the haemosporidian *Leucocytozoon tawaki* Fallis, Bisset & Allison to Fiordland crested penguins (Allison *et al.* 1978). Based on Australian experience, Gurr (1953) speculated that simuliids could possibly act as mechanical vectors of myxomatosis.

Background

There are few records of natural enemies of black flies in New Zealand. Miller (1969) recorded that *Empis otakauensis* Miller (Diptera: Empididae) captured and destroyed adults on the wing. The German wasp *Vespula germanica* (F.) (Hymenoptera: Vespidae) was recorded by Kleinpaste (1980) as capturing adults. Crosby (1975) showed that *Austrosimulium tillyardianum* Dumbleton larvae were the main prey of the two caddis-flies *Hydrobiosis parumbripennis* McFarlane and *Aoteapsyche colonica* (McLachlan) (Trichoptera).

Batson (1983) recorded two species of Microspora found in *Austrosimulium* larvae: a rare species *Hirsutusporos austrosimulii* Batson (Nosematidae), and a relatively common undescribed species of the family Thelohaniidae.

Trichomycete fungi occur as obligate symbionts in the digestive tracts of larvae (Crosby 1974): these are not parasites as suggested in Jenkins (1964). Chilcott (1979) recorded a fungal pathogen, *Coelomycidium* sp. (Chytridiomycetes: Chytridiales), infecting two *Austrosimulium* species.

Experiments have been undertaken in Auckland (Craig 1983) and Dunedin (Chilcott *et al.* 1983) to test the effectiveness of the delta endotoxin of the bacterium *Bacillus thuringiensis* var. *israelensis* (*B.t.i.*) against larvae of *Austrosimulium* species. Craig (1983) carried out her experiments under laboratory conditions using a simulated stream system. Simuliid larvae for the tests were collected from a mixed population of a non-biting species, *A. longicorne* Tonnoir (about 75%), and the biting species, *A. australense* (about 25%). She used a preparation of purified insoluble crystalline delta endotoxin from sporulated liquid cultures of *B.t.i.* derived from primary powder R153-78. The species were highly susceptible to the *B.t.i.* delta-endotoxin, with a median lethal time of 12.9 h at a concentration of 10 ppm and exposure time of 1 h. She concluded that increasing either the concentration or exposure time would not greatly increase the percentage mortality of the larvae. Chilcott *et al.* (1983) conducted field experiments against two non-biting species, *A. laticorne* Tonnoir and *A. multicorne* Tonnoir, and found that the two formulations of *B.t.i.* they used (Sandoz 402 WDC and primary powder R153-78) were effective against the larvae. They concluded that available formulations of *B.t.i.* could be used effectively in open streams against biting species if treatments were repeated at one to two week intervals, and such treatments might be economically feasible in sensitive tourist resorts where commercial considerations are important.

Importations, Releases and Recoveries

Predators

Predators of black fly larvae were imported into New Zealand from Australia between 1930 and 1932, but did not become established: the predaceous midge *Cardiocladius australiensis* Freeman (Diptera: Chironomidae), and up to four species of the dragon fly genus *Austroaeschna* (Odonata: Aeshnidae) (Cameron *et al.* 1987). The species were collected in the immediate vicinity of Canberra (35° 20′S, 149°E). *Austroaeschna* spp. larvae were liberated at Nelson (41° 18′S, 173° 19′E) and at Cass (43° 03′S, 171° 45′E); *Cardiocladius australiensis* larvae were liberated only at Nelson (DSIR files). No voucher specimens were kept of these liberations. No recoveries were made.

Austroaeschna spp. (Odonata: Aeschniidae)

About 500 larvae were sent in six consignments in November 1930 and October/November 1931; four consignments were sent to the Cawthron Institute, Nelson (DSIR files), and two to E. Percival, Christchurch, for release at Cass (Anonymous 1931). They were collected in Canberra at the Cotter River below the water supply dam, and possibly also from the Molonglo River.

Rowe (1987) suggested the larvae were collected in Tasmania, basing his evidence on a letter written by E. Percival to J.S. Armstrong on 10 July 1957, and stated that the species imported therefore was *Austroaeschna parvistigma* Martin. However, the information in the letter contradicts other evidence written at the time of the importations, and I do not regard it as reliable.

Four species of *Austroaeschna* are reasonably common in the Cotter River and surrounding streams: *A. atrata* Martin, *A. inermis* Martin, *A. multipunctata* Martin, and *A. u. unicornis* Martin (J.A.L. Watson pers. comm.). It is likely that all four species were imported, as it is unlikely such numbers of live larvae would have been identified to species: the collector, A.L. Tonnoir, was a dipterist, and the Odonata specialist, R.J. Tillyard, would not have been in a position to do much because of his administrative duties. Therefore, although the exact species composition of the larvae imported must remain uncertain, it is clear that several species of *Austroaeschna* were involved. Information on the numbers imported and released is incomplete, but enough exists to allow reasonable estimates to be made.

In November 1930 two consignments were received a week apart at the Cawthron Institute: 95 larvae were alive out of 120-150 sent. These were held in aquaria for about three weeks, before the surviving 88 larvae were released into two different parts of the Maitai River, Nelson. A consignment of probably 50-100 larvae was sent to E. Percival in November 1930, but no written information exists as to the number sent, received, or released at Cass.

In October/November 1931, 270 larvae were sent to New Zealand (CSIR 1932). Probably 180-200 were sent to Cawthron in two consignments, and probably half survived. They were held in aquaria for one to two weeks. Only 31 survived for release into Poormans Valley Stream, Nelson. One consignment of probably 70-90 was sent to E. Percival; about half survived the journey, and were released at Cass at the beginning of December (Anonymous 1931).

Cardiocladius australiensis Freeman (Diptera: Chironomidae)

Two consignments totalling 1,200 larvae were sent to Nelson in 1932 (CSIR 1932, DSIR files). Apparently they were all collected from the Molonglo River. The first consignment of 400 larvae arrived in late January; 196 survived and were immediately released into the Maitai River, Nelson, at the Council Reserve. The second consignment of about 800 arrived in early May; 581 larvae and 19 pupae survived and were also immediately released into the Maitai River at the Council Reserve.

Only one species of *Cardiocladius* is described from the Austropacific region: *C. australiensis* (P.S. Cranston pers. comm.). The paratype series of the species includes specimens collected by Tonnoir in 1931 from the Cotter River. Freeman (1961) also included the note 'larvae predacious on *Simulium* larvae' with these specimens. This information corresponds with information in a letter from Tonnoir to the Cawthron Institute in 1931 about *Cardiocladius*, and a photograph attached to the letter showing a larva feeding on a *Simulium* larva (DSIR files). There seems little doubt that the paratype series of *C. australiensis* includes material that is sympatric with the introduced stock.

Evaluation

Predators

Austroaeschna spp. and *Cardiocladius australiensis* were sent to New Zealand because of the enthusiasm of A.L. Tonnoir. When Tonnoir joined the Cawthron Institute in 1921, he was asked to gather as many facts as possible concerning black flies which could eventually be used as a basis for possible control (Tonnoir 1925). Not long after he joined the Division of Economic Entomology, Canberra, in 1929, he found these predators and arranged to send them because he thought they were effective in controlling larvae in Canberra. D. Miller was then in charge of the entomology group at the Cawthron Institute, and it would appear from some correspondence that resources were overstretched and he was not keen to begin this project (DSIR files). Therefore, the release of specimens at Nelson was done under pressure, and they may not have been released in optimal areas where there were high numbers of black fly larvae. The consignments to E. Percival in Christchurch required special journeys for release at Cass. It is probable these releases were made in more ideal areas than Nelson.

However, none of the releases was made in areas where *Austrosimulium ungulatum* or *A. australense* cause serious problems. The releases made were into streams inhabited mainly by non-target species of *Austrosimulium*, and if the predators had established it is not certain that the target species would have been controlled.

Jenkins (1964) quoted Grenier (1953) as stating these predators 'gave good control in New Zealand'. However, Grenier stated they 'would have given good results in New Zealand (aurait donné de bons resultats en Nouvelle-Zélande)', citing the report of their introduction by CSIR (1932).

Biocide

It may be possible to control *A. australense* with *Bacillus thuringiensis* var. *israelensis* in a few places, but it is unlikely that *A. ungulatum* could be controlled because of the difficulty of treating numerous small streams in dense bush surrounding main tourist areas. A further difficulty is that the flight range of these species is unknown. My observations suggest it is many kilometres, which means large areas may need to be treated before there is a significant decrease in biting pressure. The expense may not warrant such measures.

Conclusions

If further introductions are attempted, it is important they be made against target species. As the two problem *Austrosimulium* species occupy quite different habitats, each would probably require different biocontrol agents.

Acknowledgements

I thank P.S. Cranston (British Museum (Natural History), London) and J.A.L. Watson (Division of Entomology, CSIRO, Canberra) for providing information about the identities of the predators.

Literature Cited

Allison, F.R.; Desser, S.S.; Whitten, L.K. (1978) Further observations on the life cycle and vectors of the haemosporidian *Leucocytozoon tawaki* and its transmission to the Fiordland crested penguin. *New Zealand journal of zoology* 5, 371-374.

Anonymous (1931) War on sandflies. Natural enemy liberated. *New Zealand Herald 12 December 1931* 68(21054), 10.

Austin, F.J. (1967) The arbovirus vector potential of a simuliid. *Annals of tropical medicine and parasitology* 61, 189-199.

Batson, B.S. (1983) A light and electron microscopic study of *Hirsutusporos austrosimulii* gen. n., sp. n., (Microspora: Nosematidae), a parasite of *Austrosimulium* sp. (Diptera: Simuliidae) in New Zealand. *Protistologica* 19, 263-280.

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242, 51 pp.

Chilcott, C.N. (1979) *Austrosimulium* (Diptera: Simuliidae) larval pathogens in the Dunedin area and the histopathology of *Coelomycidium* species. B.Sc. (Hons) thesis, Otago University, Dunedin, New Zealand. viii + 57 pp.

Chilcott, C.N.; Pillai, J.S.; Kalmakoff, J. (1983) Efficacy of *Bacillus thuringiensis* var. *israelensis* as a biocontrol agent against larvae of Simuliidae (Diptera) in New Zealand. *New Zealand journal of zoology* 10, 319-326.

Craig, E.E. (1983) Susceptibility of *Austrosimulium* (*A.*) *australense* and *Austrosimulium* (*A.*) *longicorne* (a mixed population) and two non target species to *Bacillus thuringiensis* var. *israelensis*. M.Sc. thesis, Auckland University, New Zealand. xiv + 123 +(19) pp.

Crosby, T.K. (1974) Trichomycetes (Harpellales) of New Zealand *Austrosimulium* larvae (Diptera: Simuliidae). *Journal of natural history* 8, 187-192.

Crosby, T.K. (1975) Food of the New Zealand trichopterans *Hydrobiosis parumbripennis* McFarlane and *Hydropsyche colonica* McLachlan. *Freshwater biology* 5, 105-114.

Crosby, T.K. (1976) *Austrosimulium* (*Austrosimulium*) *dumbletoni* n.sp. from New Zealand (Diptera: Simuliidae). *New Zealand journal of zoology* 3, 17-19.

Crosskey, R.W. (1981) Geographical distribution of Simuliidae. Pp. 57-68 in Laird, M. (ed.) Blackflies: the future for biological methods in integrated control. Academic Press, London.

CSIR (1932) Entomological investigations. *Report of the Council for Scientific and Industrial Research, Australia* 6, 20-23.

DSIR, Entomology Division file BC 1/4.

Dumbleton, L.J. (1973) The genus *Austrosimulium* Tonnoir (Diptera: Simuliidae) with particular reference to the New Zealand fauna. *New Zealand journal of science* 15, 480-584.

Freeman, P. (1961) The Chironomidae (Diptera) of Australia. *Australian journal of zoology* 9, 611-737.

Grenier, P. (1953) Simuliidae de France et d'Afrique du Nord (systématique, biologie, importance médicale). *Encyclopédie entomologique (A)* 29, 1-170.

Gurr, L. (1953) Some remarks on the possible insect vectors of myxomatosis in New Zealand. *New Zealand science review* 11, 81-82.

Jenkins, D.W. (1964) Pathogens, parasites and predators of medically important arthropods. Annotated list and bibliography. *Bulletin of the World Health Organization, supplement* 30, 1-152.
Kleinpaste, R. (1980) Food of german wasps. *The weta* 3, 17.
Miller, D. (1969) Notes and records. *New Zealand entomologist* 4(2), 23-25.
Rowe, R.J. (1987) The dragonflies of New Zealand. Auckland University Press, Auckland. 260 pp.
Tonnoir, A.L. (1925) Australasian Simuliidae. *Bulletin of entomological research* 15, 213-255.

Calliphoridae, blow flies (Diptera)

A.C.G. HEATH and D.M. BISHOP

Pest Status

The Calliphoridae that most often come to notice in New Zealand are those that cause ovine myiasis (flystrike). Myiasis refers to a particular mode of feeding by dipterous larvae, on or in the body of a living vertebrate. Flystrike is a specific type of myiasis and is an extension of the carrion feeding habit of certain genera of Calliphoridae. Adult flies feed on a wide variety of animal and plant substances and are strongly attracted to moisture. They feed mainly on sweet substances such as nectar and honeydew and on the liquid products of organic decomposition, which provide the proteins essential for egg maturation. The larvae can develop on various substrates, ranging from kitchen refuse and faecal material to carrion and living animals.

Larvae spend at least three days feeding, although cold temperatures can extend this period. Two ecdyses occur during the feeding phase and the third instar larva then leaves the food to seek shelter, usually in soil or under objects lying on the surface of the ground, where the pupal stage can develop.

The first official record of flystrike in New Zealand appeared in the 1890s (New Zealand Department of Agriculture 1896), but it first came to public notice in the 1870s (Heath 1985). In the early years of the 20th century the flies mainly responsible (*Lucilia sericata* (Meigen), *Calliphora stygia* (F.) and *Chrysomya rufifacies* (Macquart) (Diptera: Calliphoridae)) became established nationwide and remain the most prevalent species reared from instances of flystrike (Heath 1985). Occasional intruders into flystrike lesions are *Calliphora quadrimaculata* (Swederus), *Calliphora hilli* Patton and *Xenocalliphora hortona* (Walker) (Calliphoridae).

The sheep is the host most commonly attacked by female Calliphoridae although in recent years, cases of flystrike in goats caused by *L. sericata* have been recorded (Heath & Bishop unpublished). The economic effects of flystrike include reduced liveweight, wool loss, pelt damage, stock deaths and control costs, amounting to about NZ$15 million annually (Heath 1985).

Background

A number of indigenous parasitoids have been reared from calliphorids in New Zealand. The braconids *Phaenocarpa antipoda* Ashmead and *Alysia stramineipes* Cameron have been known for many years (Valentine & Walker 1989). More recently a diapriid, *Antarctopria coelopae* Early (Early 1978), has been recorded from Calliphoridae, although it is restricted to coastal shingle habitat and probably only attacks larvae on beached carcasses.

The role of yet another indigenous braconid *Aphaereta aotea* Hughes & Woolcock is uncertain but its apparent willingness to attack all three main flystrike species (Heath & Bishop unpublished) implies that it could be useful in controlling calliphorids. This species was imported into Australia from New Zealand to control *Musca vetustissima* Walker (Muscidae), although the results were not encouraging (Hughes & Woolcock 1976).

The encyrtid *Tachinaephagus zealandicus* Ashmead was first described from Australia (Subba Rao 1978) and it may also be indigenous to New Zealand. Olton & Legner (1971)

considered it endemic in the southern hemisphere. This species was known as early as 1904 to parasitise calliphorids in Australia (Subba Rao 1978).

Overseas, the pteromalid *Nasonia vitripennis* (Walker) (previously known as *Mormoniella vitripennis* and *Nasonia brevicornis* Ashmead), the chalcid *Brachymeria podagrica* (= *Chalcis calliphorae* (F.)) and the braconid *Alysia manducator* (Panzer) had been known as parasitoids of Calliphoridae since 1910, 1916 and 1920 respectively (Greenberg 1971).

Despite these previous discoveries, it was not until the early 1920s that attempts to evaluate and deliberately use hymenopteran parasitoids of Calliphoridae for biological control in New Zealand were begun. This can be judged from publications of that time (e.g. Altson 1920, Johnston & Tiegs 1921) where *N. vitripennis* was eventually considered as a biological control agent despite having been first reared from *Musca domestica* L. in the U.S.A. as early as 1908 (Altson 1920). The importance of flystrike as a disease of sheep increased from the time of recognition of the first cases and eventually led to consideration of biological control of blow flies in New Zealand in the 1920s (Miller 1922).

Among the larger Hymenoptera, the accidentally imported Vespidae, *Vespula germanica* (F.) and *V. vulgaris* (L.), merit comment as their liking for insects and their apparently regular selection of Calliphoridae as prey suggest they may be important predators (Donovan 1984). It has been suggested (Black-Hawkins 1911, Madden 1981) that *V. germanica* is a major predator of blow flies. The numbers of flies collected daily are certainly impressive but there is no indication that the species taken are those involved in flystrike. Miller (1971) suggested that *V. germanica* is 'a most effective predator' of blow flies, but Thomas (1960) in an extensive study made no reference to marked population control of blow flies by wasps. Indeed, Madden (1981) suggested that abundance of wasps' nests may even be related to abundance of prey. This view seems to be supported by circumstantial evidence in that flystrike (Heath & Bishop unpublished), wasp populations (Anonymous 1987) and distribution of *V. vulgaris* have all increased in recent years.

Importations, Releases and Recoveries

The first parasitoid introduced into New Zealand, *Nasonia vitripennis*, was obtained from Australia and released in 'large numbers' at Timaru, North Canterbury, Blenheim, Hawke's Bay and Whangarei in 1922 (Miller 1922). This official liberation was preceded by a private release in Blenheim before 1922 (no date given). In neither case (Miller 1927a) was there perceived to be any effect upon blow fly numbers. This species parasitises young pupae, 24-72 hours after the completion of the third larval instar, and attacks both *L. sericata* and *Calliphora stygia*. Other hosts in New Zealand include *C. vicina* Robineau-Desvoidy, *C. quadrimaculata* and *Chrysomya rufifacies* (Valentine 1967). It can overwinter in the host pupa as a larva.

The reason given for its lack of success was that being a pupal parasitoid, *N. vitripennis* cannot locate pupae buried underground. Miller (1927a) decided (although earlier suggested by Johnston & Tiegs (1921)) that a larval parasitoid was likely to be more successful and so *A. manducator* was obtained from the United Kingdom. Between November 1926 and January 1927, three consignments of blow fly puparia (species not recorded) arrived (5,050 in all) from which 232 *A. manducator* emerged (Miller 1927b). On receipt, *A. manducator* was found to readily attack larvae of *L. sericata*, *Calliphora stygia* and *Chrysomya rufifacies* (Miller 1927b). The first field liberations of unspecified numbers of the wasp were made onto maggot-infested carcasses and offal in 1926 and early 1927 at Blenheim, Canterbury, Weraroa (near Levin) and Kaitaia (Miller 1927b). Almost 150 releases were subsequently made between 1928 and 1935 over the whole country between Auckland and Central Otago, with both islands receiving similar attention (DSIR files).

A series of reports (Cawthron Institute 1935, 1937, Miller 1936, 1939) noted that *A. manducator* was well established and had spread naturally from the lowlands of Marlborough to the inland hill country. Rates of parasitism by *A. manducator* on blow flies in the field were never established (Cawthron Institute 1935), although Gourlay (1930) had considered it to have a greater efficiency in the control of sheep blow flies than either *Tachinaephagus zealandicus* or *N. vitripennis*. In addition to the three species cited by Miller (1927b), *A. manducator* was subsequently recovered from *Calliphora vicina* and *C. quadrimaculata* as well as representatives of the dipteran families Muscidae and Sarcophagidae (Valentine 1967).

In a further attempt to bring pressure to bear on blow flies, Miller (1927a) obtained from Australia four puparia said to contain the encyrtid *T. zealandicus*. No other records of subsequent introductions or details of releases have been found. Some may have taken place (although native *T. zealandicus* may have been involved) as Gourlay (1930) stated that *T. zealandicus* occurred in greater numbers than *N. vitripennis*. The basis for this quantitative assessment is not given although *T. zealandicus* was said to be interfering with *A. manducator* (Gourlay 1930, Miller 1928) so some recoveries must have been made. It is possible that *T. zealandicus* was already present in New Zealand, either as a native or as a result of an earlier, unrecorded introduction before it was introduced from Australia. No introductions are recorded by Cameron *et al.* (1987).

Female *T. zealandicus* are able to search effectively and can survive well at low host densities so that calliphorids in isolated breeding habitats can suffer high prevalence of parasitism (Olton & Legner 1974). The females are invariably attracted to the larvae of flies breeding in decomposing plant or animal matter. The main flystrike species *C. stygia* and *L. sericata* are parasitised, together with *C. vicina* and *C. quadrimaculata* (Valentine 1967).

The only other hymenopteran introduced to New Zealand for control of blow flies was the chalcid *Brachymeria podagrica*. Miller (1921) noted that this larval parasitoid was introduced from Australia in 1919 but no release site is mentioned. It does not appear to have been recovered subsequently although its size, like 'a small housefly' (Johnston & Tiegs 1921), makes it unlikely to have been overlooked.

Evaluation

In the absence of any deliberate survey it is difficult to assess either the geographic distribution or the influence of parasitoids of Calliphoridae in New Zealand. In a recent flystrike survey, relying upon random collections, over 600 samples of blow fly larvae were received between April 1984 and June 1987 (Heath & Bishop unpublished). Parasitoids were reared from larvae from only seven samples, but *A. manducator* was not among them. From five of these samples *T. zealandicus* was reared out of *L. sericata* and *Calliphora stygia* puparia. The cases of flystrike occurred in the North Island at Gisborne (two cases), Wairoa, Levin and Wairarapa (one case each). Percentage parasitism (assessed in only four cases) ranged from 4.2% to 20.0% in the samples received. The preponderance of *T. zealandicus* even in such a small sample may support the comments of Gourlay (1930) about the possibility of interference with *A. manducator* by *T. zealandicus* despite the apparently satisfactory establishment and spread of the former (e.g. Miller 1936, 1939).

Concern was also expressed by Miller (1927b) that *N. vitripennis* might interfere with *A. manducator* as it did in the U.K., although Altson (1920) was not particularly concerned on this point. The occasional involvement of *T. zealandicus* in multiple parasitism with *A. manducator* (Miller 1928) might be seen as a potential impediment to the activities of *A. manducator* yet this species appears (at least at an early stage of its introduction) to have successfully established (Gourlay 1930). One factor which may limit the success of *A. manducator* is its reluctance to attack larvae in faecal matter (Myers 1926). Flystrike and faecal matter are often closely associated so that parasitoids attracted to such material, e.g. *T. zealandicus* and *Aphaereta aotea* might be expected to be found more frequently in larvae from cases of flystrike.

The prevalence of a pupal parasitoid such as *N. vitripennis* cannot be measured from collections of larvae and can only be gauged from puparia found near a corpse or close by where a case of flystrike has run its course. In these situations the pupal parasitoid is likely to be a less effective control measure than a larval parasitoid because the number of hosts it can reach is more restricted (Johnston & Tiegs 1921).

Among the endemic parasitoids of Calliphoridae, *Alysia stramineipes*, *Phaenocarpa antipoda*, *Antarctopria coelopae* and *Aphaereta aotea*, only the last species has been recorded from cases of flystrike (Heath & Bishop unpublished). One case came from a sheep in the Wairarapa in March 1986 from which 15.0% of puparia were parasitised and another in May 1986 involved a goat at Wanganui, where 15.4% of the pupae were parasitised. In both cases *L. sericata* was the host species involved. Although *A. aotea* readily parasitises *Calliphora stygia*, *C. vicina* and *Chrysomya rufifacies* in the laboratory, these species have not yet been found affected in the field (Heath & Bishop unpublished). Its association with the sarcophagid *Hybopygia varia* (Walker) (= *Sarcophaga milleri* Johnston & Tiegs) was noted by Hughes *et al.* (1974).

The specimens of *A. aotea* which Hughes *et al.* (1974) examined for biological control potential against *Musca vetustissima* were sent by R.A. Cumber, who had recovered them from *H. varia* puparia and identified the wasp as a cause of high mortality in its host. However, in earlier work, Cumber (1960) noted *H. varia* as being parasitised by *Ericydnus* sp. The latter is a parasitoid of mealybugs (A.K. Walker pers. comm.) and was apparently a misidentification. Whether in fact *Ericydnus* sp. was used in error for *A. aotea* is probably not in doubt but further confusion is added by J. Noyes (in A. K. Walker pers. comm.) who has examined specimens labelled *Ericydnus* and found them to be *T. zealandicus*. It would appear as if *H. varia* can be parasitised by both *A. aotea* and *T. zealandicus*.

Specimens of *A. aotea* have been taken from the surface of cattle faeces at Wairoa, Kaitoke, Wallaceville, Opunake and Hamilton between January and May (Heath & Bishop unpublished). The wasp was also found on goat and sheep faeces at Wallaceville in May 1986 (Heath & Bishop unpublished). If *Ericydnus* is a misidentification for *A. aotea* then Cumber & Eyles (1961) show it to be distributed over most of the North Island. No records are known from the South Island.

The impact of the recently discovered *A. aotea*/calliphorid association cannot be gauged at present. Its absence (and that of other parasitoids) in earlier surveys (Heath 1985) is puzzling. The possibility that climatic conditions which have apparently favoured an increase in blow fly numbers have also encouraged an extension of the host range of *A. aotea* must be considered. It is easily reared in the laboratory and deliberate inundative releases are planned, initially into areas where flystrike is severe, in an attempt to reduce the disease. Inoculative releases will subsequently be made into areas where the wasp is absent.

Aphaereta aotea has a wide host range within the Calliphoridae and is mainly a gregarious parasitoid with numbers of one to 58 emerging per pupa (Heath & Bishop unpublished). Its potential as a blow fly parasitoid was not suspected by Hughes *et al.* (1974). Among its advantages are its attraction for faecal matter from a variety of ruminants and its wide distribution. Apart from locations mentioned earlier (Heath & Bishop unpublished), Cumber & Eyles (1961) found it (presumably as *Ericydnus*) over most of the North Island on crops and in pasture. Heath & Bishop (unpublished) found *A. aotea* in chou moellier and surmised that the height of the crop allowed the weakly-flying wasp the opportunity to attain the backs of sheep moving through the crop, thus allowing access to larvae in flystrike wounds. Cumber & Eyles (1961) suggested that Diptera breeding in rotting brassicas may possibly act as hosts to *A. aotea*, but there was no evidence to support the view. The presence of this species on pasture is fortuitous for goats, as wasps can enter footrot infections which are occasionally flystruck.

Apart from the original reports there are no records of subsequent collections of *Phaenocarpa antipoda*, *Alysia stramineipes* or *Antarctopria coelopae* from Calliphoridae.

Conclusions

To be effective as agents for control of Calliphoridae, hymenopterous parasitoids need to have access to aggregations of blow fly larvae such as occur on carcasses in early stages of decay or in cases of myiasis. This gives female wasps the opportunity to oviposit in as many larvae as possible. Being weak fliers it is possible that wasps may have difficulty seeking out host larvae from any great distance. This assumed poor host-seeking ability, together with the continued existence of the parasitoids would seem to suggest that there are many sources of hosts for calliphorid-specific species such as *Alysia manducator* and *Phaenocarpa antipoda* to guarantee their survival. There is also the possibility that a wider, but undiscovered range of hosts exists, although scarcity of *A. manducator* and *P. antipoda* may contradict such a possibility. The more common parasitoids (based on recent recoveries) such as *Tachinaephagus zealandicus* and *Aphaereta aotea* may be more successful because of their wide host range among the dipteran families (see Valentine 1967). In particular, *A. aotea* may have considerable potential as a biological control agent because a widespread dipteran, *Hybopygia varia*, which breeds in cattle and sheep dung, (Cumber 1960, Heath & Bishop unpublished) is a common host and offers a refuge in the absence of calliphorid larvae.

As flystrike continues to be a significant economic problem in New Zealand, the overall effects of parasitoids (and predators) have presumably been minimal. In fact occurrence of ovine myiasis has increased in recent years. It has been suggested (Legner & Olton 1968) that parasitoids limit host populations by parasitising the larval survivors, i.e. those surviving to the third stage which by definition must be the 'fittest'. This may be the case within an experimentally closed system, but in the field, where distances between aggregations of potential hosts can be relatively vast to a weakly flying wasp, the chance of significant impact on calliphorids must be remote.

A policy of inoculative releases of parasitoids onto numerous and widespread sources of larval hosts may be the next step if biological control of Calliphoridae by Hymenoptera is to be taken seriously.

Literature Cited

Altson, A.M. (1920) The life-history and habits of two parasites of blowflies. *Proceedings of the Zoological Society of London* 15, 195-243.

Anonymous (1987) Wasp threat to nature's balance. *Evening Post, Wellington* 15 October.

Black-Hawkins, M. (1911) Some observations on *Vespa germanica*. *Zoologist* 15, 457-463.

Cameron, P.J.; Hill, R.L.; Valentine, E.W.; Thomas, W.P. (1987) Invertebrates imported into New Zealand for biological control of invertebrate pests and weeds, for pollination, and for dung dispersal, from 1874 to 1985. *DSIR bulletin* 242, 51 pp.

Cawthron Institute (1935) Annual report, 12.

Cawthron Institute (1937) Annual report, 17.

Cumber, R.A. (1960) The insect complex of sown pastures in the North Island. X. Insects revealed in studies of soil, turf and dung. *New Zealand journal of agricultural research* 3, 253-267.

Cumber, R.A.; Eyles, A.C. (1961) Insects associated with the major fodder crops in the North Island. IV. Hymenoptera. *New Zealand journal of agricultural research* 4, 390-408.

New Zealand Department of Agriculture (1896) Annual Report, 19-20.

Donovan, B.J. (1984) Occurrence of the common wasp, *Vespula vulgaris* (L.) (Hymenoptera: Vespidae) in New Zealand. *New Zealand journal of zoology* 11, 417-427.

DSIR, Entomology Division, file BC 1/4.

Early, J.W. (1978) New Diapriinae (Hymenoptera: Diapriidae) from the South Island and subantarctic islands of New Zealand. *Journal of the Royal Society of New Zealand* 8, 207-228.

Gourlay, E.S. (1930) Some parasitic Hymenoptera of economic importance in New Zealand. *New Zealand journal of science and technology* 11, 339-343.

Greenberg, B. (1971) Flies and disease. Vol I. Princeton University Press, Princeton, U.S.A. 856 pp.
Heath, A.C.G. (1985) Fly-strike in New Zealand. Pp. 15-18 in Dear, J.P., Calliphoridae (Insecta: Diptera). *Fauna of New Zealand* 8.
Hughes, R.D.; Woolcock, L.T. (1976) *Aphaereta aotea* sp. n. (Hymenoptera: Braconidae), an alysiine parasite of dung breeding flies. *Journal of the Australian Entomological Society* 15, 191-196.
Hughes, R.D.; Woolcock, L.T.; Ferrar, P. (1974) The selection of natural enemies for the biological control of the Australian bushfly. *Journal of applied ecology* 11, 483-488.
Johnston, T.H.; Tiegs, D.W. (1921) On the biology and economic significance of the chalcid parasites of Australian sheep maggot-flies. *Proceedings of the Royal Society of Queensland* 33, 99-128.
Legner, E.F.; Olton, G.S. (1968) Activity of parasites from Diptera: *Musca domestica*, *Stomoxys calcitrans*, and species of *Fannia*, *Muscina*, and *Ophyra*. II. At sites in the Eastern Hemisphere and Pacific area. *Annals of the Entomological Society of America* 61, 1306-1314.
Madden, J.L. (1981) Factors influencing the abundance of the European wasp (*Paravespula germanica* (F.)). *Journal of the Australian Entomological Society* 20, 59-65.
Miller, D. (1921) Sheep maggot-flies and their allies. A New Zealand investigation. *New Zealand journal of agriculture* 22, 321-324.
Miller, D. (1922) Sheep maggot-fly control by insect parasites. The introduction of *Nasonia brevicornis*. *New Zealand journal of agriculture* 24, 211-212.
Miller, D. (1927a) Parasite control of sheep maggot-flies. Notes on current work. *New Zealand journal of agriculture* 34, 1-4.
Miller, D. (1927b) Parasite control of sheep maggot-flies. Establishment of *Alysia manducator* in New Zealand. *New Zealand journal of agriculture* 35, 219-220.
Miller, D. (1928) Establishment of beneficial insects in New Zealand. Summary of recent work under Agriculture Department. *New Zealand journal of agriculture* 37, 193-195.
Miller, D. (1936) Biological control of field crop and animal pests. *New Zealand journal of science and technology* 18, 592-593.
Miller, D. (1939) Blow-flies (Calliphoridae), and their associates in New Zealand. *Cawthron Institute monograph* 2, 68 pp.
Miller, D. (1971) Common insects in New Zealand. A.H. & A.W. Reed, Wellington, New Zealand. 178 pp.
Myers, J.G. (1926) The habits of *Alysia manducator* (Hym., Braconidae). *Bulletin of entomological research* 17, 219-229.
Olton, G.S.; Legner, E.F. (1974) Biology of *Tachinaephagus zealandicus* (Hymenoptera: Encyrtidae), parasitoid of synanthropic Diptera. *Canadian entomologist* 106, 785-800.
Subba Rao, B.R. (1978) A revision of *Tachinaephagus* Ashmead (Hymenoptera: Encyrtidae) with descriptions of four new species. *Bulletin of entomological research* 68, 65-73.
Thomas, C.R. (1960) The European wasp (*Vespula germanica* Fab.) in New Zealand. *New Zealand Department of Scientific and Industrial Research information series* 27, 74 pp.
Valentine, E.W. (1967) A list of the hosts of entomophagous insects in New Zealand. *New Zealand journal of science* 10, 1100-1210.

Muscidae, muscid flies (Diptera)

N.P. MARKWICK, R.L. HILL, and D.J. ALLAN

Pest Status

The family Muscidae is one of a number of families of flies containing species associated with man through their feeding and breeding habits and collectively called synanthropic flies. Besides the muscid species named below, other synanthropic species occur in the families Calliphoridae, Sarcophagidae, Psychodidae, and Drosophilidae.

The best known muscid species is the common house fly *Musca domestica* L. recorded as a nuisance and health hazard to man since the earliest times e.g. the Plagues of Egypt (Exodus 8:24). Miller (1932) suggested that *Musca domestica* reached New Zealand sometime prior to 1856, and showed by several quotations from the period that the house fly was well established by the 1870s. He was a little incredulous at suggestions in the literature that the house fly was responsible for the reduction of native blow flies, and that it had probably arrived by way of Australian cattle ships (Bathgate 1870, 1897).

House flies breed in animal manure and excrement, particularly where this is accumulated in animal and poultry houses, in garbage, and in decaying organic matter especially compost, ensilage, and grass clippings. The feeding habits of the house fly, involving regurgitation of liquid from the crop, ensure easy transmission of disease to food for human consumption. The transmission of diseases such as typhoid, cholera, amoebiasis, bacillary dysentery, and the milder diarrhoeas have been attributed to the house fly (West 1951).

A blood-sucking muscid *Stomoxys calcitrans* (L.), the stable fly, is particularly well known around milking-sheds where it causes considerable nuisance by biting stock and by buzzing, making the cattle nervous and difficult to manage (Emberson 1984). There is considerable disagreement between experts as to whether *Stomoxys calcitrans* decreases the amount of milk produced in dairy cows exposed to them (Miller *et al.* 1973). However, there is good evidence that average populations of *S. calcitrans* (approximately 50 per calf) reduce weight gains and feeding efficiency and hence cause significant differences in the costs of production of quality slaughter beef (Campbell *et al.* 1977).

The larvae of *S. calcitrans* live in decaying plant material such as rubbish heaps, ensilage stacks and spilled feed. This fly bears a strong resemblance to the house fly but its biting mouthparts distinguish it from *M. domestica* and so it is sometimes called the biting house fly or dog fly (West 1951).

Other flies that frequent houses and outbuildings include *Muscina stabulans* (Fallén) (the true stable fly) and a species from the family Fannidae, *Fannia canicularis* (L.), (the lesser house fly). *M. stabulans* is a non-biting stable fly the larvae of which develop in similar habitats to those of the house fly but are distinguished from them by the character of the posterior spiracles. *F. canicularis* is smaller than the house fly and its larvae are strikingly different with many spinelike appendages.

Background

Biological control of synanthropic flies through the redistribution of natural enemies around the world was promoted in the late 1960s by E.F. Legner and his co-workers from the University of California, and F.D. Bennett and F.J. Simmonds from the CIBC. Extensive surveys of the parasitoids of synanthropic flies were conducted in the western hemisphere

(Legner *et al.* 1967) and the eastern hemisphere and Pacific area (Legner & Olton 1968). Included in the latter survey were collections from four sites around Christchurch and six sites in the Auckland area. Samples were generally taken from accumulated dung, the major breeding medium for the target species: *M. domestica*, *S. calcitrans*, and species of *Fannia*, and *Muscina*. Fly parasitoids recorded from these species in New Zealand included *Spalangia cameroni* Perkins, *S. endius* Walker, and *S. nigroaenea* Curtis (Hymenoptera: Pteromalidae), along with *Tachinaephagus zealandicus* Ashmead (Hymenoptera: Encyrtidae) and *Trichopria* sp. (Hymenoptera: Diapriidae).

Worldwide, these surveys found that four sympatric species, *Muscidifurax raptor* Girault & Sanders, *S. cameroni*, *S. endius* and *S. nigroaenea* (Hymenoptera: Pteromalidae), were the predominant pupal parasitoids in most areas. However, *M. raptor* was absent from New Zealand although it was abundant in similar climatic areas (Legner & Olton 1968). Legner & Olton (1968) suggested that *M. raptor* should be considered a strong candidate for introduction into areas where it was absent because of its predominance and because of the higher fecundities of certain strains. They also recommended dissemination of *T. zealandicus* from the southern hemisphere to areas in the northern hemisphere where it did not exist.

In September 1968, F.J. Simmonds of CIBC wrote to DSIR asking if they had considered the possibility of biological control of house flies. He stated that CIBC had a number of parasitoid species available in quantity (or could breed them) sufficient for field liberation and could obtain predators too in co-operation with the University of California. R.A. Cumber accepted the offer and so arrangements for the importation of several species of fly parasitoids were made (DSIR files).

Importations, Releases and Recoveries

A total of six shipments of some 26,400 parasitised fly puparia was received by Entomology Division, DSIR, between 17 January 1969 and 29 September 1969 from the CIBC at Curepe, Trinidad, where a programme of fly parasitoid rearing had been in operation for a number of years (Cumber DSIR files). Table 69.1 gives details of the size and dates of importations of these parasitoids.

Some confusion as to the exact identification of the species of fly parasitoids obtained was evident in early reports (Cumber DSIR files). Apart from the species changes cited in Table 69.1, the *Muscidifurax raptor* complex was reviewed by Kogan & Legner (1970) and some of the strains were renamed as species. For example, *Muscidifurax raptor* (south-western strain) was renamed *M. zaraptor*, and *M. raptor* (Puerto Rican strain), a uniparental species, was renamed *M. uniraptor*. Prior to the September shipment, Legner made determinations of the DSIR cultures and indicated that they could be referred only to *Muscidifurax zaraptor* Kogan & Legner, *M. uniraptor* Kogan & Legner, and *Pachycrepoideus vindemiae* (Rondani).

The shipment of fly parasitoids which arrived in September 1969 (Table 69.1) supposedly contained three species. *Sphegigaster* sp. was not isolated from the culture (Cumber DSIR files) and subsequent identification of the *Spalangia* sp. culture by Legner yielded only *S. endius* (Markwick DSIR files). This species was already present in New Zealand and the newly introduced strains were not recognisably different from the resident strain.

All parasitoids obtained were reared on *M. domestica* pupae. Tests showed that all species also attacked and parasitised *S. calcitrans* and *Hybopygia varia* (Walker) (Diptera: Sarcophagidae) (Cumber DSIR files). Habitats of these three hosts provided a wide range of possible liberation sites including rubbish dumps, ensilage stacks, cut-grass dumps, domestic compost, fields with heavy infestations of *H. varia* in cattle dung, stable and cattle dung aggregations, poultry runs, and so on.

Table 69.1 Fly parasitoid importation dates and the number of parasitised puparia received from CIBC West Indian Station in 1969 (from R.A. Cumber DSIR files).

Shipped as	Date Received	Number of parasitised puparia received
**Spalangia nigra* Latreille	Jan. and Feb.	6,000
Muscidifurax raptor	Jan. and Feb.	3,000
M. raptor	Jan. and Feb.	3,000
M. raptor	January	2,000
Pachycrepoideus vindemiae	January	1,000
**Sphegigaster* sp.	Apr. to Jun.	8,000
Spalangia nigra	September	2,000
Spalangia sp. (Barbados)	September	2,000
+*Sphegigaster* sp. (South African strain)	September	1,400

*Cumber (DSIR files) stated that these shipments of *Spalangia nigra* and *Sphegigaster* sp. reverted to *Pachycrepoideus vindemiae* and no liberations were made of either *S. nigra* or *Sphegigaster* sp. from these shipments.

+Cumber (DSIR files) was not able to isolate *Sphegigaster* sp.

Widespread liberations were made throughout the Auckland province between late February and mid-September 1969 (Cumber DSIR files). From October 1969 to June 1970, in addition to further northern liberations, parasitoids were released in widely separated sites in the south of the North Island and in the South Island (Figs 69.1, 69.2, in these figures 'corrected' species identifications are used). Shipments were also made to Niue Island, the Tokelau Islands, and the New Hebrides (Cumber DSIR files). In all, some 320,000 parasitoids belonging to species of the genera *Muscidifurax*, *Pachycrepoideus*, and *Spalangia* were released at 435 sites (Cumber DSIR files).

Several recoveries of fly parasitoids were made from ensilage stacks and compost in April 1971 by Cumber but all proved to be species of *Spalangia*, mostly *S. cameroni* or *S. endius*. At the same time, Valentine was surveying poultry house fauna in Nelson. He reported that *T. zealandicus* and *Spalangia* spp. were the abundant species (mostly *S. cameroni* and *S. endius*), but there was still no sign of *Muscidifurax* spp. or *P. vindemiae* (DSIR files).

In 1955, R.A. Cumber sent a small number of *Pachylister chinensis* Quensel (Coleoptera: Histeridae) from Western Samoa to Entomology Division, DSIR, at Nelson. This beetle is predatory on fly larvae. The progeny of these beetles were released onto fly-infested dung in a greenhouse but were never recovered (W.P. Thomas pers. comm.). The dung-burying beetle *Copris incertus* Say (Coleoptera: Scarabaeidae) was also imported from Western Samoa, not as a biological control agent, but to remove dung in which muscid flies can breed (Thomas 1960). It has established in an area near Whangarei but it appears to be of little benefit to farmers (Blank *et al.* 1983).

Figure 69.1 Release sites and the numbers of house fly parasitoids released from February to September 1969.
(M) = *Muscidifurax* spp., (P) = *Pachycrepoideus vindemiae*.
Remaining numbers released comprised a mixed culture of these species. Area codes from Crosby *et al.* (1976).

Evaluation

In 1973, Cumber (DSIR files) stated that very low percentages of a species resembling a *Muscidifurax* species had occurred in the relatively small number of areas sampled so far and that *S. endius* was appearing commonly. However, its status was complicated by the fact that this species was already present in the country. Farmers in the Helensville area had reported a marked drop in the number of biting flies at milking times and reports of reduced fly populations had also come from the Auckland area, Whangarei, and Wanganui. He also noted that post-release samples from Niue Island produced *S. endius*, no parasitoids of this species being detected prior to release.

Comparisons of intrinsic rates of increase, overwintering responses, and interspecific relationships led to the following conclusions (Markwick 1974) regarding the likely establishment of the four fly parasitoids; *Muscidifurax zaraptor*, *M. uniraptor*, *Spalangia endius*, and *Pachycrepoideus vindemiae*. Firstly, Markwick (1974) stated that the case for introducing *P. vindemiae* was tenuous since it apparently occupied similar habitats and niches to the *Muscidifurax* spp. and was competitively inferior to them.

Secondly, should *S. endius* compete directly with the *Muscidifurax* species it too would probably be eliminated very quickly. Weight was given to this argument recently by G.

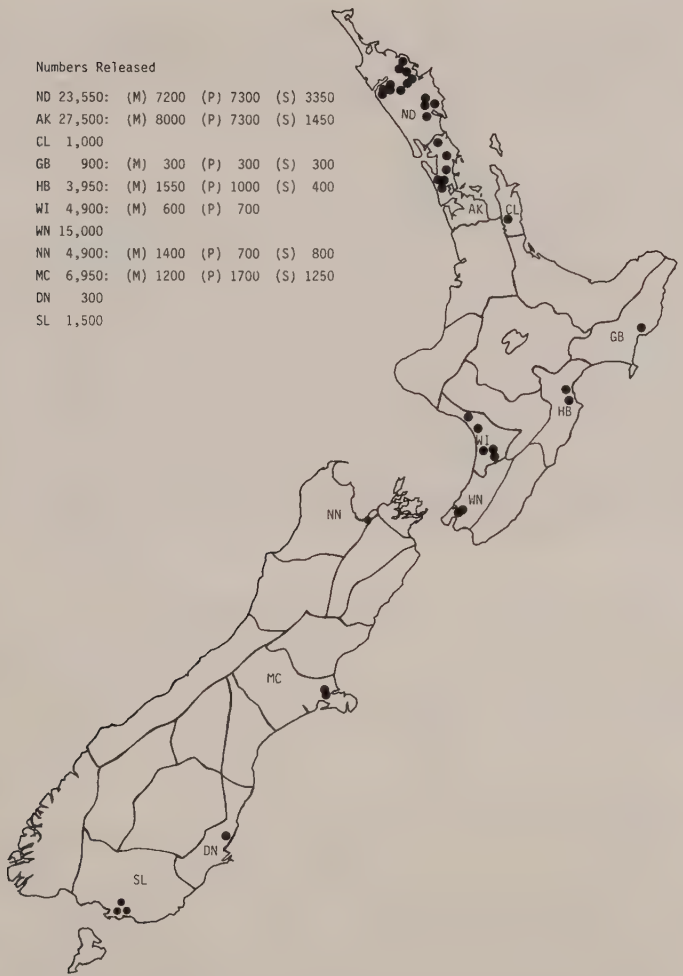


Figure 69.2 Release sites and numbers of house fly parasitoids released from October 1969 to June 1970.
(M) = *Muscidifurax zaraptor* and *Muscidifurax uniraptor*
(P) = *Pachycrepoideus vindemiae*
(S) = *Spalangia endius*.
Remaining numbers released comprised a mixed culture of these species.

Gaffney (pers. comm. 1988), Agricultural Biological Control Services, California. He stated that, after inundative releases of *Muscidifurax* spp. and *S. endius* into poultry houses, the latter species was seldom recovered. However, it is strongly suspected that *S. endius* would eventually occupy a different habitat (both micro- and macro-climatically). In Southern California, for example, *M. uniraptor* and *S. endius* are found together but flourish at different times of the year (Legner & Brydon 1966). In New Zealand *S. endius* could occupy areas not available to *M. uniraptor* since the latter lacks a diapause stage and hence would be restricted to areas with mild winters. Further, Legner (1967) found that *S. endius* was a better searcher than the *Muscidifurax* species and tended to parasitise more hosts deeper in the host habitat.

Finally, the two *Muscidifurax* spp. may avoid direct competition and occupy different niches. The two species do not naturally occur sympatrically: *M. uniraptor* is found in high humidity areas in Puerto Rico and *M. zaraptor* in low humidity areas of the south-western U.S.A. (Kogan & Legner 1970) and experimental results reflect these humidity preferences (Markwick 1974). Also, unlike *M. uniraptor*, *M. zaraptor* has a diapausing overwintering stage. The conclusion, based on laboratory experimentation and on the literature, was that these last three species of fly parasitoids had a good chance of establishment. This could only be substantiated by field recoveries.

In 1975-76 a survey was carried out in one type of breeding habitat to find out whether the imported parasitoids had become established there (Hill & Allan DSIR files). Puparia were collected from 16 sites between Kaitaia and Gisborne on up to three occasions through the summer. At each site, two staff searched the edge of a silage stack for 30 minutes. The puparia collected were returned to the laboratory and were examined. Those which had not already emerged were placed in dry, corked tubes, up to 50 per tube. After two weeks at ambient temperature all flies and parasitoids which had emerged were counted and removed. Puparia were examined individually to determine whether a fly had emerged from the end of the puparium or a whether a parasitoid had emerged from a characteristic hole chewed in the side. The fate of each puparium was recorded and the parasitoids were identified as far as possible. The puparia which had emerged before they were collected were also examined in this way. The results of this survey are summarised in Table 69.2.

Table 69.2 A summary of results from a survey (1975-76) of fly puparia from 16 sites between Kaitaia and Gisborne to determine the incidence of fly parasitoids (from Hill & Allan DSIR files).

Host	Number of puparia reared	Parasitoids which emerged		
		Spalangia cameroni	*Spalangia endius*	Others*
Stomoxys calcitrans	1627	31	68	19
Musca domestica	491	20	37	11

*see text

The indigenous species *Spalangia endius* and *S. cameroni* were the dominant parasitoids. They appeared to have no host preference but *S. endius* seemed more common than *S. cameroni* in early summer and less common in late summer. These two species accounted for approximately 82% of all the parasitoids reared. The next most common species was an unidentified alysiid species. Ten specimens reared from fly puparia from Hikurangi (near Whangarei) and one from Pokuru (near Hamilton) closely resembled *Muscidifurax* species. Unfortunately the specimens retrieved from amongst the debris in the rearing tubes were of poor quality and could not be identified further. The maximum parasitism recorded was 34%. Overall, only 7.3% of *Stomoxys calcitrans* and 13.7% of *Musca domestica* puparia were parasitised. If the specimens described above were introduced *Muscidifurax* species, then these parasitoids do not regulate fly populations, at least not in this habitat.

More recently however, Holloway (1984) recorded that two species of pteromalid wasps, *Spalangia endius* and *Muscidifurax uniraptor* had emerged from puparia of *Fannia canicularis* collected in poultry houses in Hawke's Bay. The same two species of fly parasitoids also emerged from puparia of *Fannia albitarsis* Stein (Diptera: Fanniidae) collected from poultry manure in the same area. This shows that *Muscidifurax uniraptor* at least has established in the Hawke's Bay area but a further extensive survey is required to determine its distribution and effectiveness.

Pachycrepoideus vindemiae has not been recorded since the fly parasitoids were liberated. This is consistent with predictions by Legner & Olton (1968) who suggested that there was very little promise for this species as a biological control agent since it was rarely found on synanthropic fly hosts. It is also consistent with predictions made by Markwick (1974).

Conclusions

The fact that two of the fly parasitoid species released in this programme have been recovered recently from puparia of *Fannia canicularis* in Hawke's Bay (Holloway 1984) shows that some of the species have become established. It is especially interesting that the recoveries were made in this area since only a relatively small number of releases were made there in 1970 (Fig. 69.2). This points to the need for a large scale survey to determine whether some or all of the species have established, in which areas and in which habitats. The level of parasitism of the various fly species should also be examined to determine if parasitoids can effectively control fly populations. If such a survey of fly parasitoids indicated that they had established and were an effective control in some pockets e.g. poultry houses, it may well be useful to facilitate the spread of these parasitoids to all such areas.

Before further biological control introductions are considered, the pest status of flies on stock and in poultry houses should be examined. House flies, at least, retain a considerable nuisance value around houses throughout New Zealand as is evidenced by the continued popularity of fly sprays.

Acknowledgements

The review of releases is largely based on reports by R.A. Cumber of work which he and D.J. Allan carried out, assisted by other DSIR staff.

Literature Cited

Bathgate, A. (1870) *Transactions of the New Zealand Institute* 3, 137-41.

Bathgate, A. (1897) *Transactions of the New Zealand Institute* 30, 266-79.

Blank, R.H.; Black, H.; Olson, M.H. (1983) Preliminary investigations of dung removal and flight biology of the Mexican dung beetle *Copris incertus* in Northland (Coleoptera: Scarabeidae). *New Zealand entomologist* 7, 360-364.

Campbell, J.B.; White, R.G.; Wright, J.E.; Crookshank, R.; Clanton, D.C. (1977) Effects of stable flies on weight gains and feed efficiency of calves on growing or finishing rations. *Journal of economic entomology* 70, 592-594.

Crosby, T.K.; Dugdale, J.S.; Watt, J.C. (1976) Recording specimen localities in New Zealand: an arbitrary system of areas and codes defined. *New Zealand journal of zoology* 3, 69 + map.

DSIR, Entomology Division, file BC 1/4.

Emberson, R.M. (1984) Livestock pests. Pp. 235-246 in Scott R.R. (ed.) New Zealand pests and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand. 373 pp.

Holloway, B.A. (1984) Larvae of New Zealand Fanniidae (Diptera: Calyptrata). *New Zealand journal of zoology* 11, 239-258.

Kogan, J.; Legner, E.F. (1970) A biosystematic revision of the genus *Muscidifurax* (Hymenoptera: Pteromalidae) with descriptions of four new species. *Canadian entomologist* 102, 1268-1290.

Legner, E.F. (1967) Behaviour changes the reproduction of *Spalangia cameroni*, *Spalangia endius*, *Muscidifurax raptor*, and *Nasonia vitripennis* (Hymenoptera: Pteromalidae) at increasing fly host densities. *Annals of the Entomological Society of America* 60, 819-826.

Legner, E.F.; Brydon, H.W. (1966) Suppression of dung-inhabiting fly populations by pupal parasites. *Annals of the Entomological Society of America* 59, 638-651.

Legner, E.F.; Olton, G.S. (1968) Activity of parasites from Diptera; *Musca domestica*, *Stomoxys calcitrans*, and species of *Fannia*, *Muscina*, and *Ophyra*. II. At sites in the Eastern Hemisphere and Pacific area. *Annals of the Entomological Society of America* 61, 1306-1314.

Legner, E.F.; Bay, E.C.; White, E.B. (1967) Activity of parasites from Diptera: *Musca domestica*, *Stomoxys calcitrans*, *Fannia canicularis*, and *F. femoralis*, at sites in the western hemisphere. *Annals of the Entomological Society of America* 60, 462-468.

Markwick, N.P. (1974) A comparative study of four house-fly parasites (Hymenoptera: Chalcidoidea). Ph.D. thesis, University of Victoria, Wellington, New Zealand, 333 pp.

Miller, D. (1932) The biology and economic status of New Zealand Muscidae and Calliphoridae. – Part 1. Historical review. *Bulletin of entomological research* 23, 469-476.

Miller, R.W.; Pickens, L.G.; Morgan, N.O.; Thimijan, R.W.; Wilson, R.L. (1973) Effect of stable flies on feed intake and mite production of dairy cows. *Journal of economic entomology* 66, 711-713.

Thomas, W.P. (1960) Notes on a preliminary investigation into the habits and life cycle of *Copris incertus* Say (Coprini: Coleoptera) in New Zealand. *New Zealand journal of science* 3, 8-14.

West, L.S. (1951) The housefly. Comstock Publishing Company, New York, U.S.A. 584 pp.

Vespula germanica (F.), German wasp and *Vespula vulgaris* (L.), common wasp (Hymenoptera: Vespidae)

B.J. DONOVAN

Pest Status

The German wasp *Vespula germanica* (F.), which is native to the western Palaearctic, was established in New Zealand by 1945 and now occurs throughout the country (Donovan 1978). The common wasp *Vespula vulgaris* (L.) is native to the Holarctic, but in 1983 it was first recorded as established in New Zealand at Dunedin (Donovan 1983). It was probably present in Wellington several years previously (Donovan 1984). Common wasps have now colonised much of the South Island and widely spaced areas of the North Island. Both species probably entered New Zealand as hibernating queens in articles of commerce.

Queens of both species emerge from hibernation in spring and nests are founded from about September to December. Nests grow rapidly from December and the number of workers reaches a peak from February to about April. Drones appear from about January and new queens from about March. Nests of common wasps usually collapse by late May, but some German wasps' nests may survive the winter, begin to produce workers again by spring, and may grow to two or three cubic metres by the beginning of their second winter. There are no New Zealand records of common wasps' nests surviving a winter, or of German wasps' nests surviving a second winter.

Wasp numbers increased soon after establishment, and since then they have become a public nuisance. People and animals have been stung, at least a few animals and one person fatally. The fear of people being stung has closed several schools for at least a few days and has sometimes forced a ban on the consumption of food and drink in playgrounds because of the likelihood of attracting wasps. Large numbers of wasps have caused campers and tourists to flee from campgrounds, picnic spots and public reserves. Forestry operations have been curtailed where wasps and their nests have been abundant. The frightening appearance of wasps in vehicles is known to have caused accidents. Ripening fruits, especially grapes, plums, peaches and nectarines are foraged upon by wasps.

Walton & Reid (1976) found that during 1974/75, wasps destroyed or damaged 14,000 beehives at a cost to beekeepers of NZ$134,000.

In native beech forests wasps consume large volumes of insect honeydew, and prey upon many native insects. Some native birds flee wasp-infested areas (H. Moller pers. comm.). Where wasp numbers in forests are high, the disturbance to the ecological faunal web is likely to be severe.

Wasps are considered to have some beneficial characteristics. Perrott (1975) reported a belief that blow fly (Diptera: Calliphoridae) populations were reduced by wasp predation and that wasps played a minor role in pollination. Walton & Reid (1976) noted that one beekeeper believed that wasps destroyed many wild beehives, thus reducing the number of diseased beehives.

Background

In 1922, *Nasonia vitripennis* (Walker) (Hymenoptera: Pteromalidae) was introduced into New Zealand from Australia for the control of calliphorid flies (Chapter 68, Miller 1922). Gauss (1970) reported that in Germany two pupae of *Dolichovespula saxonica* (F.) (Vespidae) were attacked by *N. vitripennis*.

In New Zealand, Thomas (1960) found no signs of parasitism in 300 dissected nests of *V. germanica*. Similarly, with one exception (see below), all naturally-occurring nests of *V. germanica* (about 80) and *V. vulgaris* (about 120) dissected from 1979 to 1987 as part of a wasp parasitoid mass multiplication project, have been free of enemies. Spradbery (1973) listed approximately 150 insect species associated with wasps in the Holarctic, and Edwards (1980) reported about 400 organisms. R.A. Cumber of the Entomological Research Station, stationed at Palmerston North, examined the possibilities for biological control of *V. germanica* in New Zealand (Thomas 1960). Three agents were reported upon. The beetle *Metoecus paradoxus* (L.), (Coleoptera: Rhipiphoridae) was considered to have no potential for control because of a very low rate of attack. The moth *Aphomia sociella* L. (Lepidoptera: Galleriidae) was known to destroy a small number of nests annually in England, but bumble bee nests were also destroyed. Nematodes were associated with, and apparently parasitised, wasps' nests in England. No further action was taken at that time.

Thomas (1960) quotes A.T. Gaul who described the ichneumonid *Sphecophaga burra* (Cresson) (Hymenoptera: Ichneumonidae) as an excellent parasitoid of North American vespines. *Melittobia chalybii* Ashmead (Hymenoptera: Eulophidae) was known to attack vespines, but its non-specificity detracted from its value. Thomas (1960) concluded that *S. burra* was probably the most promising of the parasitoids of *Vespula* spp. The genus *Sphecophaga* is Holarctic in distribution. Four names have been applied, but Townes & Townes (1962) believed there was only one species, *S. vesparum* (Curtis), with a North American subspecies *S. v. burra* (Cresson), and a European subspecies *S. v. vesparum* (Curtis).

As recently as 1980, female *S. vesparum* within wasps' nests were thought to oviposit into wasp larvae, which continued to grow normally, to spin a capping to their cell, and then begin to pupate. Larval *S. vesparum* were then believed to grow within the wasp's pupal gaster and emerge at larval maturity to spin cocoons within the cell between the base of the cell and the now dead wasp pupa (Edwards 1980). Apart from the position of cocoons, this has proven not to be true.

Importations, Releases and Recoveries

Sphecophaga vesparum burra (Cresson) (Hymenoptera: Ichneumonidae)

In 1978, R.D. Akre of Washington State University, U.S.A. offered to supply the author with cocoons of *S. v. burra*. In August and September 1979, 798 cocoons in four shipments were received at DSIR Lincoln. The cocoons were from nests of *Vespula atropilosa* (Sladen) (Hymenoptera: Vespidae). By June 1980, 81 females and three males had emerged. In quarantine, 49 first generation cocoons were produced in comb of *V. germanica*. Four cocoons and two female parasitoids raised in quarantine were released into field nests of German wasps at DSIR Lincoln from 30 November 1979 to 18 February 1980. Nest dissections in March and May 1980 showed no attack.

Subsequent attempts to break diapause of imported prepupae in cocoons did not succeed, except that during the next 18 months a few females emerged sporadically and unpredictably. Several cocoons were produced on German wasps in quarantine, but by late 1982 the North American population was extinct. During this work oviposition was found to occur mainly into cells containing newly pupated wasps. Eggs were deposited on the anterior end of a host, and the parasitoid larva fed externally on the host gaster (Donovan & Read 1987).

Sphecophaga vesparum vesparum (Curtis) (Hymenoptera: Ichneumonidae)

During 1980, K.P. Carl of the CIBC European Station, Delémont, Switzerland, made collections of *S. v. vesparum* for Entomology Division, DSIR. Three shipments totalling 1,280 cocoons within combs of the common wasp collected in Switzerland, Germany and Austria, were received at DSIR Lincoln during September and October 1980. Three further shipments totalling 7,524 cocoons were received during October and November 1981 from nests in Switzerland and Austria: 781 cocoons were from seven nests of *Dolichovespula saxonica*, and 6,743 from nests of the common wasp. All shipments contained some adult female parasitoids, ranging from a few to several score, many of which were dead or dying. From 33 female parasitoids that emerged in quarantine soon after importation in 1980, three generations were bred on German wasps and 161 cocoons were produced.

During late January 1984, nests of the recently discovered common wasp became available in Christchurch for the first time (Donovan 1984). On 11 December 1984, three female *S. v. vesparum* produced 11 cocoons in comb of the common wasp. Late in December the last of the imported parasitoid cocoons produced 14 females. From these, a continuously breeding population of parasitoids was established. By July 1985, 13 consecutive generations of parasitoids had been raised on common wasps, and about 1,500 overwintering cocoons and several hundred adults had been produced. Parasitoids were also propagated for several generations on German wasps.

From early March to mid-May 1985, parasitoids raised in quarantine were released into seven common wasps' nests and six German wasps' nests in Canterbury at Southbridge, Lincoln, Christchurch and at Mt Thomas (North Canterbury). Subsequent examination of these nests showed that six common wasps' nests and three German wasps' nests had been attacked. At least one generation of parasitoid adults had emerged in four common wasps' nests and one German wasps' nest (Donovan & Read 1987).

By early October 1985, a further 858 overwintering parasitoid cocoons had been released in specially constructed release boxes and one natural wasps' nest site in Christchurch and Mt Thomas, Canterbury. From 10 September to 8 October 1985, about 81 male parasitoids and 66 female parasitoids were liberated over the same areas. By late January 1986, 308 of the cocoons in release boxes were recovered to obtain adult parasitoids for mass-rearing at Lincoln. By this time, approximately one-third of the cocoons showed adult emergence.

On 6 November 1986, *S. v. vesparum* was recovered from an overwintered German wasps' nest which had been collected in suburban Christchurch two days earlier. In a small portion of comb which was removed for parasitoid propagation, a recently formed 'yellow' parasitoid cocoon was discovered, but there was no opportunity to recover the bulk of the nest for examination. This nest was 4.8 km from the nearest parasitoid release site.

Further mass-rearing of the parasitoid commenced at Lincoln in December 1986. By mid-September 1987, 31,080 'yellow' cocoons had been produced. By late September 1987, these had been distributed over the South Island as follows: Buller 420; North Canterbury 945; Mid-Canterbury 5,145; South Canterbury 945; Central Otago 1,155; Dunedin 1,050; Marlborough and Marlborough Sounds 7,980; Nelson 7,350; Otago Lakes 1,155; Southland 1,050; Waikato 1,050 and Westland 2,835. Release boxes each containing 105 cocoons were sited in areas where wasps were pestiferous to people. These areas included a wide variety of habitats, such as residential suburbs of towns and cities, country holiday sites, beach front picnic areas and forested campgrounds.

On 5 May 1988, two active nests of the common wasp were excavated at Pelorus Bridge, Marlborough, and were found to be attacked by the parasitoid. In one nest, 33 m from the nearest release box, there were 471 parasitoid stages. In the other nest, 625 m from the nearest release box, there were 1,034 stages. From the two nests, a total of at least 86 winged adults had emerged, presumably to seek other nests to attack. The two nests contained a total of 555 'yellow' cocoons (H. Moller pers. comm.). In the subsequent seasons these remaining cocoons would have produced winged parasitoids. From the three release boxes in the area, 266 parasitoids had emerged.

Metoecus paradoxus (L.) (Coleoptera: Rhipiphoridae)

The rhipiphorid beetle parasitoid of social wasps, *Metoecus paradoxus*, was present in combs of the first two shipments of the common wasp imported from CIBC European Station in September and October 1980. In the first shipment, there were five dead adults and five adults alive. The live adults were provided with dilute honey in water and pollen pellets removed from honey bees. Weathered wood was also supplied as an oviposition site, but within nine days all adults had died without ovipositing.

There was one moribund adult in the second shipment, plus five larvae and two pupae. Because of the presence of *Melittobia acasta* (Walker) (Hymenoptera: Eulophidae), the shipment was destroyed.

Combs of the common wasp imported from CIBC European Station in October 1981 produced four adult *Metoecus paradoxus*, but all died within three days. The shipment also contained 110 eggs of *M. paradoxus* which were scattered over the surface of a piece of rotting, dry wood which measured about 80 mm x 15 mm x 12 mm. These eggs had been laid at the CIBC European Station. At room temperature, triungulins began emerging on 11 March 1982. By 24 June 1982, 38 had emerged. Although the triungulins were transferred to comb of *V. germanica* which contained immatures of all stages of development, no triungulins were seen to feed, and no wasp larvae were destroyed. Further emergence of triungulins occurred after September 1982 but again none developed on German wasp comb. By December 1982 all remaining eggs had collapsed.

Other species

Two shipments of comb of the common wasp from the CIBC European Station received at Lincoln during October 1980, contained *Melittobia acasta*. All stages were found on large wasp larvae and early pupae, and within cocoons of *S. v. vesparum*. This species is not host-specific and so all material of these shipments was incinerated.

During October and November 1981, two nests of *Dolichovespula saxonica* containing *Dibrachys boarmiae* (Walker) (Hymenoptera: Pteromalidae), collected in Switzerland and Austria, were received at Lincoln from CIBC European Station. Subsequently, in 1983, x-ray examination showed that two *S. v. vesparum* cocoons from one of these *Dolichovespula saxonica* nests contained dead *Dibrachys boarmiae*. All infested material was destroyed. This is the first record of *D. boarmiae* from Vespidae and from *S. v. vesparum*. *D. boarmiae* was referred to as *D. vesparum* (Ratzeburg) by Donovan & Read (1987) but has since been identified as *D. boarmiae* by Z. Bouček (pers. comm.).

Evaluation

The recovery of one cocoon of *S. v. vesparum* from a *V. germanica* nest, and a total of 1,505 stages from two *V. vulgaris* nests indicates that the parasitoid is established. Because *S. v. vesparum* adults emerge from cocoons over at least three and possibly four years, the majority of adults to emerge from the 31,080 cocoons distributed during mid-1987 will not have emerged until about 1990. At best, little impact on wasp numbers can be expected for several years.

Conclusions

Mass-rearing of *S. v. vesparum* has been achieved for the first time and will continue for several years. The bulk of cocoons will be released throughout the North Island, but there will be further releases in the South Island. The planned release of thousands of additional parasitoids throughout New Zealand and over a variety of habitats should greatly enhance the potential for reduction in wasp numbers.

Acknowledgements

Sincere thanks to R. Akre, Washington State University, Pullman, Washington State, U.S.A. and to K. Carl, CIBC European Station, Delémont, Switzerland, for supplying *S. v. burra* and *S. v. vesparum* respectively. Special thanks go to H. Moller for locating the parasitoid in two nests of the common wasp and for allowing me to use his data.

Literature Cited

Donovan, B.J. (1978) The German wasp *Vespula germanica* (F.) (Hymenoptera: Vespidae) in New Zealand. Pp. 49-63 in Papers presented at a honeydew seminar, Christchurch. Ministry of Agriculture and Fisheries, Advisory Services Division.

Donovan, B.J. (1983) The common wasp is here. *New Zealand beekeeper* 180, 9-10.

Donovan, B.J. (1984) Occurrence of the common wasp, *Vespula vulgaris* (L.) (Hymenoptera: Vespidae) in New Zealand. *New Zealand journal of zoology* 11, 417-427.

Donovan, B.J.; Read, P.E.C. (1987) Attempted biological control of social wasps, *Vespula* spp., (Hymenoptera: Vespidae) with *Sphecophaga vesparum* (Curtis) (Hymenoptera: Ichneumonidae) in New Zealand. *New Zealand journal of zoology* 14, 329-335.

Edwards, R. (1980) Social wasps, their biology and control. Rentokil Ltd., East Grinstead, U.K. 398 pp.

Gauss, R. (1970) Beitrag zur Kenntnis von Parasitoiden bei aculeaten Hymenopteren. *Zeitschrift für angewandte Entomologie* 65, 239-244.

Miller, D. (1922) Sheep maggot-fly control by insect parasites. The introduction of *Nasonia brevicornis*. *New Zealand journal of agriculture* 24, 211-212.

Perrott, D.C.F. (1975) Factors affecting use of mirex-poisoned protein baits for control of European wasp (*Paravespula germanica*) in New Zealand. *New Zealand journal of zoology* 2, 491-508.

Spradbery, J.P. (1973) Wasps. University of Washington Press, Seattle, U.S.A. 408 pp.

Thomas, C.R. (1960) The European wasp *Vespula germanica* Fab.) in New Zealand. *New Zealand Department of Scientific and Industrial Research information series* 27, 74 pp.

Townes, H.; Townes, M. (1962) Ichneumon-flies of America north of Mexico 3: Subfamily Gelinae, Tribe Mesostenini. *Bulletin of the United States National Museum* 216, 523-529.

Walton, G.M.; Reid, G.M. (1976) The 1975 New Zealand European wasp survey. *New Zealand beekeeper* 38, 26-30.

abdominalis, *Aphelinus* 4, 34
Abies spp. 271, 297
abnormis, *Leptomastidea* 231
abnormis, *Leptomastix* 232
abnormis, *Paraleptomastix* 232
abnormis, *Tanaomastix* 232
absoluta, *Gnorimoschema* 119
absoluta, *Phthorimaea* 119
absoluta, *Scrobipalpula* 121
Acacia decurrens 231
Acacia spp. 10, 207, 208
Acaena agnipila 313
Acaena anserinifolia 309, 313-315
Acaena caesiiglauca 313
Acaena novae-zelandiae 313
Acaena profundeicinis 313
Acaena spp. 313, 314
acaenae, *Ucona* 313, 314
Acalitus essigi 357
acantha, *Pediobius* 102, 103
acanthoides, *Carduus* 339, 341
acasta, *Melittobia* 398
Aceria genistae 369
Achaearanea veruculata 156, 193
Achatina fulica 93
Achroia grisella 115
Achrysocharoides splendens 290, 291, 292
Acyrthosiphon kondoi 1, 2, 3-7, 33, 84
Acyrthosiphon pisum 1, 2, 3-7, 33, 84
Acyrthosiphon spp. 33, 34, 57
Adalia bipunctata 57
Adelencyrtoides unicolor 226
Adelencyrtus aulacaspidis 180
Adelges nordmannianae 297
Adelina tenebrionis 17, 20
Adelina sp. 17
adenophora, *Ageratina* 309, 317-320
adonidum, *Dactylopius* 224
adonidum, *Pseudococcus* 224
advena, *Gyranusoidea* 226, 233
aegyptiaca, *Icerya* 207
Aenoplex carpocapsae 164
Aenoplex carpocapsas 164
aeruginosa, *Microcystis* 321
aethiopoides, *Microctonus* 25, 27, 28
affinis, *Pseudococcus* 223, 224, 226, 227, 228, 232, 233, 234
Agasicles hygrophila 325, 326, 328, 329
Agathiella sp. 190
Agathis rufipalpis 75-76, 77, 78, 79, 81, 82, 84
Agathis unicolor 121, 122, 123
Agathis unicolorata 123
Agathis sp. 75-76, 77, 122
Ageratina adenophora 309, 317-320
Ageratina riparia 317
agilis, *Anystis* 162
Agistemus longisetus 218
agnipila, *Acaena* 313
Agnomus strobilorum 277
Agonopterix nervosa 368
Agonopterix ulicetella 368, 369
Agrilus ruficollis 358
Agromyzidae 45-49
Agrotis ipsilon 51-54, 69, 107, 115, 116, 144
Agrotis ipsilon aneituma 51
Agrotis spp. 52
Alamella mira 226
alaskensis, *Rhyssa* 304
albicillata, *Mesoleuca* 358
albicosta, *Coleophora* 368
albidus, *Aphytis* 179
albisignata, *Idatiella* 162, 184, 218
albisignata, *Sejanus* 162, 184, 218, 246
albitarsis, *Fannia* 392
albopictus, *Mesostenus* 213
albostriata, *Ctenoplusia* 67, 115, 116
alcis, *Hexamera* 39
alcyonipennella, *Coleophora* 74, 76
aldrichi, *Hyperecteina* 11
aldrichi, *Isocheta* 11
Aleyrodes proletella 251
aleyrodis, *Aschersonia* 251
algal blooms 309, 321-324
alligator weed 310, 325-330
Alloxysta infuscata 106
Alloxysta victrix 56, 106
almond 155, 217
Alternanthera philoxeroides 310, 325-330, 332
Altica carduorum 343, 344
Altica virescens 313, 314
altissima, *Melilotus* 75
Alysia manducator 382, 383, 385
Alysia stramineipes 381, 384
Amblymerus ?*apicalis* 277
Amblyseius cucumeris 246
Amblyseius fallacis 219, 247
Amblyseius longispinosus 246
American elm 197
americana, *Ulmus* 197
amoena, *Rhyssa* 300, 304, 305
Amylostereum areolatum 299
Amynothrips andersoni 325
amyoti, *Glaucias* 147
Anabaena flos-aquae 321
Anacharis zealandica 57, 197
Anacystis cyanea 321
Anagrus armatus 184, 185
Anagrus sp. 184
Anagyrus fusciventris 233, 234
Anagyrus sp. 226, 233
Anaphes atomarium 23, 24, 25
Anaphes nitens 267
Anaphes sp. 23
Anaphoidea nitens 267
Anarhopus sydneyensis 226
Anarsia spartiella 368
anceps, *Rhopus* 226
ancylivorus, *Macrocentrus* 155, 158
andersoni, *Amynothrips* 325
Angitia cerophaga 138
Angitia fenestralis 137
angulatus, *Blepharidopterus* 165, 218, 219, 246
anilitatis, *Lophocheilus* 12, 14
Anisoplaca ptyoptera 368
anisopliae, *Metarhizium* 40, 41, 116
annulata, *Nyctemera* 361
annulatus, *Myzocallis* 307
annulatus, *Tuberculatus* 255, 307-308

Anodontura sp. 13
anserinifolia, *Acaena* 309, 313-315
antarcticum complex, *Monomorium* 162
Antarctopria coelopae 381, 384
Anthoboscinae 11
Anthocoridae 218
Anthocoris musculus 165, 218, 219, 246
Anthocoris nemorum 165, 218, 246
Antholcus varinervus 314
anthracnose 257
Anthrocnodax sp. 246
antiphona, *Plutella* 135, 139
antipoda, *Phaenocarpa* 381, 384, 385
?*antipodum*, *Goniozus* sp. 191
antipodus, *Saropogon* 9
antiqua, *Rhacodineura* 202
ants 88, 163, 213, 215, 239
Anystis agilis 162
Anystis baccarum 162
Aonidiella aurantii 177, 178, 180
aotea, *Aphaereta* 381, 383, 384, 385
Aoteapsyche colonica 375
Apanteles arisba 292
Apanteles bicolor 292
Apanteles circumscriptus 290
Apanteles circumscriptus group 290
Apanteles demeter 188, 189
Apanteles glomeratus 129, 130, 131, 132
Apanteles kazak 88, 89, 90
Apanteles marginiventris 90
Apanteles plutellae 136, 139
Apanteles rubecula 129, 130, 132
Apanteles ruficrus 44, 52, 53, 54, 68, 69, 70, 71, 87, 107, 108
Apanteles scutellaris 122, 124
Apanteles sicarius 188
Apanteles subandinus 122, 123, 124, 125
Apanteles ?*subandinus* 122
Apanteles tasmanicus 188, 189, 190
Apanteles sp. ?*ruficrus* 188
Apanteles spp. 52, 77, 90, 132, 292
Aphaereta aotea 381, 383, 384, 385
Aphelinidae 56
Aphelinus abdominalis 4, 34
Aphelinus flavus 307
Aphelinus mali 145, 198
Aphelinus subflavescens 307-308
Aphelinus sp. 105
Aphelopus typhlocybae 185
Aphididae 55-66
aphidis, *Pachyneuron* 106
aphidis, *Zoophthora* 105
aphidium, *Dendrocerus* 35
Aphidius eadyi 4, 5, 6
Aphidius ervi 4, 5, 6, 7, 105
Aphidius picipes 4
Aphidius pisivorus 4
Aphidius rhopalosiphi 105, 106
Aphidius smithi 4, 5-6, 7
Aphidius urticae 4
aphids 55-66, 218, 347
  cereal 201
  hop 201
  lucerne 201
Aphis lanigera 197
Aphodius spp. 10
Aphomia sociella 396
Aphycus variolosus 258
Aphytis albidus 179
Aphytis chilensis 179, 180
Aphytis chrysomphali 180
Aphytis diaspidis 179, 180, 181
Aphytis mytilaspidis 179, 180
Apiaceae 11
?*apicalis*, *Amblymerus* 277
Apion fuscirostre 348
Apion scutellare 368
Apion ulicis 369, 370
Apistephialtes caudatus 164
Apium nodiflorum 332
Aponogeton distachyus 332
apple leafcurling midge 171-175
apple leafroller 187
apple mealybug 224
apple mussel scale 177, 178
apples 62, 155, 158, 161, 171, 174, 177, 178, 179, 181, 183, 187, 190, 192, 193, 197, 201, 217, 218, 223, 227, 228, 229, 233, 247, 289, 359
apricots 161, 201, 217, 218, 263
Aprostocetus zosimus 102, 103
Apterygothrips collyerae 218
aquatic macrophytes 331-336
aquaticum, *Myriophyllum* 332
arator, *Heteronychus* 1, 11, 14, 17-21
arborea, *Coriaria* 241
arbovirus 375
Archipinae 192
archipine – see Archipinae
Arctotheca calendula 97
areator, *Gelis* 77, 81
?*areator*, *Gelis* sp. 77
areator, *Hemiteles* 81
arecae, *Chryseococcus* 313, 314
arecae, *Dactylopius* 313
areolaris, *Dacnusa* 45
areolatum, *Amylostereum* 299
argentifera, *Chrysodeixis* 67, 68, 115
Argentine stem weevil 23-26
argentinensis, *Disonycha* 326-327, 328-329
argentinensis, *Stethantyx* 98
Aridelus sp. 282
Ariphron tryphonoides 12
arisba, *Apanteles* 292
armatus, *Anagrus* 184, 185
armigera, *Eucelatoria* 88, 89
armigera, *Helicoverpa* 44, 70, 87-91, 115, 116, 117, 144
armigera conferta, *Helicoverpa* 87
armoured scales 177
armyworm 124
Arrhenophagus chionaspidis 180
Arthrocnodax sp. 217, 218
articulatus, *Juncus* 332
Artogeia rapae 129
arvense, *Cirsium* 309, 341, 343-345
arvense, *Trifolium* 73
Aschersonia aleyrodis 251

Ascogaster carpocapsae 164
Ascogaster quadridentata 158, 164, 167
Asilidae 10
asilids – see Asilidae
Asolcus basalis 112
Aspergillus flavus 327
aspersa, *Helix* 93-95
Asphondylia ulicis 368
Aspicolpus hudsoni 213
aspidioti, *Zelaphycus* 180
Aspidiotus nerii 178, 180, 277
Aster spp. 67
Asteraceae 45
Asterodiaspis minus 257, 258
Asterodiaspis quercicola 257, 258
Asterodiaspis variolosa 257, 258
Asterodiaspis spp. 255, 257-262
asterolecanii, *Metaphycus* 258, 259
ASW – see Argentine stem weevil
ater, *Bruchidius* 348
ater, *Hylastes* 255, 271-275
athalia, *Mellicta* 351
Athene noctua 204
atomaria, *Paropsis* 283
atomarium, *Anaphes* 23, 24, 25
atrata, *Austroaeschna* 376
atratus, *Cygnus* 333
atricornis, *Phytomyza* 446
atropilosa, *Vespula* 396
atropos, *Micromeriella* 19
atychioides, *Heirodons* 191
Aucklandella sp. 188
aulacaspidis, *Adelencyrtus* 180
Aulacaspis rosae 177, 178, 180
aurantii, *Aonidiella* 177, 178, 180
aurea, *Notodytes* 40
auricularia, *Forficula* 163, 189, 201-205
australense, *Austrosimulium* 375-379
australensis, *Cardiocladius* 376
Australian leaf mining sawfly 255
Australian leafroller 187
australicum, *Trichogramma* 116
australiensis, *Cardiocladius* 377
australiensis, *Cryptoscenea* 227, 234
australis, *Cerodontha* 45
australis, *Empoasca* 183
australis, *Rubus* 314
australis, *Scolypopa* 241-244
Australoglypta latrobei 190
Austroaeschna atrata 376
Austroaeschna inermis 376
Austroaeschna multipunctata 376
Austroaeschna parvistigma 376
Austroaeschna unicornis unicornis 376
Austroaeschna spp. 376-377
Austroletes colensonis 171
austrosimulii, *Hirsutusporos* 375
Austrosimulium australense 375-379
Austrosimulium laticorne 376
Austrosimulium longicorne 376
Austrosimulium multicorne 376
Austrosimulium tillyardomyia 375
Austrosimulium ungulatum 375, 377
Austrosimulium spp. 373
autumnalis, *Odontria* 13
aversa, *Persectania* 115
Avicennia spp. 213
aviculare, *Solanum* 67, 119, 213
axenana, *Epalxiphora* 191
Azolla pinnata 332

B.t.i. – see *Bacillus thuringiensis* var. *israelensis*
baccarum, *Anystis* 162
baccata, *Gibberella* 178
Bacillus popilliae 10
Bacillus thuringiensis 53, 90, 116, 132, 135
Bacillus thuringiensis var. *israelensis* 376, 378
Bacillus spp. 10
bacteria 121, 129
bacteriophora, *Heterorhabditis* 11, 12
bactrae, *Trichogramma* 68
bactrae, *Trichogrammatoidea* 67, 115
bactrae fumata, *Trichogrammatoidea* 188
Baker's mealybug 224
bakeri, *Copidosoma* 70
Balanococcus diminutus 223, 224
Balanococcus poae 223, 224, 226, 234
Balanococcus spp. 227
?*balteatus*, *Episyrphus* 61, 63
banded clover casebearer 73-85
barbatum, *Praon* 4, 5, 6
barberi, *Sympherobius* 61, 63, 232
barley 39, 43, 51, 101, 103, 105
barley grass 101
barley yellow dwarf virus 55
barrosi, *Morphodexia* 13
Barypus clivinoides 13
basalis, *Asolcus* 112
basalis, *Trissolcus* 111, 112, 113, 114
bassiana, *Beauveria* 63, 74
batis, *Thyatira* 358
bdellid mites 29
Bdellodes lapidaria 29, 30, 31
beans 43, 67, 87, 89, 111, 112, 143, 248
beans, seedling 201
Beauveria bassiana 63, 74
Beauveria densa 116
Beauveria sp. 24, 121, 162, 163
beech 395
beehives 395
bees 241
beet 45, 201
beetles 105
beneficà, *Pseudoleucopis* 264
Berothidae 295
berryfruit 145, 146, 178, 187, 245, 246, 247, 248, 357, 359
betacea, *Cyphomandra* 119, 251
bethylid sp. – see Bethylidae
Bethylidae 188
Betula spp. 289
BGA – see bluegreen lucerne aphid
bibionis, *Steinernema* 30, 39, 41, 214, 215
bicolor, *Apanteles* 292
bicolor, *Tetracnemoidea* 226
bicoloripes, *Paraleurocerus* 70
bicolorus, *Ctenochares* 68

bifasciata, *Comperiella* 181
bifidus, *Stethorus* 218, 246
biformis, *Odiaglyptus* 226
Bigonicheta setipennis 202
Bigonicheta spinipennis 202, 203
bimaculata, *Chrysophtharta* 281, 283
binaevatus, *Scymnus* 232
binocula, *Drepanacra* 197
bipunctata, *Adalia* 57
bipustulatus, *Rhizophagus* 272
birds 10, 39, 93, 94, 129, 136, 163, 189, 202, 204, 258, 281, 335, 395
Biscirus lapidarius 29
biting flies 373
biting house fly 387
black beetle 17-21
black cutworm 51, 52
black flies 373, 375
black nightshade 67
black pine bark beetle 271-275
black scale 179, 180, 237-240
black swan 333
blackberry 309, 314, 357-360
blackberry bud moth 357
blackberry leaf midge 358
blackberry rust 357, 359
blackbird 93
blackcurrants 201, 223, 226
blancardella, *Phyllonorycter* 289, 291
Blastocrithidia caliroae 147, 149, 150, 151
Blepharidopterus angulatus 165, 218, 219, 246
blow flies xii, 381-386, 395
blue gum scale 179, 180
bluegreen lucerne aphid 3-7, 33, 55
boarmiae, *Dibrachys* 398
boerneri, *Pineus* 295
bonariensis, *Listronotus* 1, 23-26
Bonnetia comta 52
borage 67
boscii, *Inostemma* 172, 174
Botanophila jacobaeae 363-364
Botanophila seneciella 363
Bothriocephalus gowkongensis 334
boysenberry 359
Brachycaudatus helichrysi 361
Brachymeria phya 190, 191, 192
Brachymeria podagrica 382, 383
Brachymeria rubripes 191, 192
Brachymeria teuta 190, 191, 192
Brachymeria sp. 189, 190, 191, 192
Bracon gelechiae 121, 122, 124
Bracon osculator 77, 78, 82
Bracon variegator 77, 78, 79, 83, 84
braconid – see Braconidae
Braconidae 56, 188, 281
Brassica napus 55
Brassica napus var. *oleifera* 47
Brassica oleracea var. *ramosa* 46
Brassicaceae 129, 251
brassicae, *Brevicoryne* 55, 58
brassicae, *Liriomyza* 45, 46, 47, 48
brassicae, *Pieris* 130, 132
brassicas xii, 9, 23, 43, 46, 47, 48, 55, 67, 93, 111, 112, 135, 140, 384
brevicornis, *Ephialtes* 81
brevicornis, *Nasonia* 382
brevicornis, *Scambus* 77, 81
brevicornis, *Tetracnemoidea* 225, 230, 232, 233, 234
Brevicoryne brassicae 55, 58
brevifacies, *Trigonospila* 156-157, 190, 191, 192, 193
brevipilosa, *Pseudelaphroptera* 11, 12, 13, 14
broom 310, 347-349
broom twigminer 348
brounii, *Hungariella* 225
brounii, *Tetracnemoidea* 225
brounii, *Tetracnemus* 225
brown garden snail 93-95
brown owl 204
brown rot 155
brown soft scale 153-154
Bruchidius ater 348
Bruchidius villosus 348
brussels sprouts 129
Bryobia praetiosa 217
buddleia 67
bumble bee 396
burra, *Sphecophaga* 396
butterfly bush 201

cabbage 129, 140, 143
cabbage aphid 56
cabbage blight 55
cabbage trees 192
cabbage whitefly 251
caesiiglauca, *Acaena* 313
calceolariae, *Pseudococcus* 223, 224, 225, 227, 230, 231, 232, 233, 234
calcitrans, *Spalangia* 388
calcitrans, *Stomoxys* 387, 388, 392
calendula, *Arctotheca* 97
California red scale 177, 178
Californian thistle 309, 343-345
californica, *Chrysopa* 233, 234
californica, *Chrysoperla* 231
californica, *Coccinella* 58
californica, *Moranila* 237, 238, 239
californicus, *Sympherobius* 61, 63, 232, 234
Caliroa cerasi 147-152
caliroae, *Blastocrithidia* 147, 149, 150, 151
Calliephialtes messor 164
Calliphora hilli 381
Calliphora quadrimaculata 381, 382, 383
Calliphora stygia 381, 382, 383, 384
Calliphora vicina 382, 383, 384
calliphorae, *Chalcis* 382
calliphorid flies – see Calliphoridae
Calliphoridae 373, 381-386, 387
Callitriche stagnalis 332
cameroni, *Spalangia* 388, 389, 392
Campoletis chlorideae 89, 90
Campoletis sonorensis 90
Campoletis spp. 90
Campoplex haywardi 122, 123, 124
cana, *Procissio* 9
Canada thistle 343
canadensis, *Elodea* 331, 332

canary-vine 129
cane spot 357
canicularis, *Fannia* 387, 392, 393
caninae, *Mesoleius* 149
cape gooseberry 119
capensis, *Catherimeris* 19
capensis, *Microphthalma* 18
capeweed 97
capillatus, *Neomolgus* 30, 31
Capparidaceae 129
capsicum 67, 87, 111, 119
Capsidae 173
capsids – see Capsidae
capsiformis, *Nabis* 3, 4, 33, 57, 74
Carabidae 10, 11, 13, 14, 17, 18, 24
carabids – see Carabidae
carbonaria, *Periscepsia* 52, 53
Carcelia illota 88, 89
Cardiastethus sp. 218, 246
cardinalis, *Rodolia* xii, 145, 207, 208-209, 210
Cardiocladius australiensis 376, 377
cardui, *Urophora* 343-344
carduorum, *Altica* 343, 344
Carduus acanthoides 339, 341
Carduus nutans 309, 339-342
Carduus pycnocephalus 339, 340, 341
Carduus tenuiflorus 339, 340, 341
Carduus spp. 339, 340
Carmichaeliae 368
carnations 97
carnea, *Chrysoperla* 60, 62, 64
carpenteri, *Dendrocerus* 6
Carpinus spp. 289
carpio, *Cyprinus* 333, 334
Carpocapsa pomonella 161
carpocapsae, *Aenoplex* 164
carpocapsae, *Ascogaster* 164
carpocapsae, *Mastrus* 164, 166
carpocapsae, *Nosema* 163
carpocapsas, *Aenoplex* 164
carrot 93, 97
Carya sp. 289
Casinaria sp. 77, 81
Castanea spp. 289, 307
Casuarina spp. 207
Catherimeris capensis 19
Catoblemma mesotaenia 265
caudatus, *Apistephialtes* 164
caudatus, *Ephialtes* 164
caudatus, *Liotryphon* 157, 164, 165-166, 167
caudiglans, *Typhlodromus* 246
cauliflower 129
cavus, *Dibrachys* 204
Cecidomyiidae 56, 218, 246
celery 143, 201
Cententer cinerea 11
Centrodora scolypopae 242, 243
cephalonica, *Corcyra* 116
Cerambycidae 214
cerasi, *Caliroa* 147-152
Ceratophyllum demersum 332, 333
Cercospora eupatorii 318, 319
cereal aphids 201
cereals 9, 23, 43, 45, 57, 105, 106
  spring 105
  winter 105
Cermatulus nasalis 51, 88, 115, 147, 189, 269, 281
Cerodontha australis 45
Cerodontha denticornis 45
Cerodontha sp. 45
cerophaga, *Angitia* 138
cerris, *Quercus* 258, 291
cervinata, *Wiseana* 39
Ceuthorhynchidius horridus 340
Ceutorhynchus litura 343, 344
sp. nr. *chabrias*, *Diglyphus* 46
chalcid, chalcid wasps, chalcids – see Chalcididae
Chalcididae 172, 209, 268
chalcidoids 25
Chalcis calliphorae 382
Chalcis sp. 189
chalcites, *Plusia* 67
chalybeus, *Orcus* 179, 180, 238, 258, 263, 264, 265
chalybii, *Melittobia* 396
Chamaecytisus palmensis 348, 369
Chamaemyiidae 57, 295
charoba, *Tetrastichus* 102
charybdis, *Paropsis* xi, 255, 267, 281-287
Chelonus contractus 77, 79, 82, 84
Chelonus sp. nr. *contractus* 79
Chelonus curvimaculatus 121, 123
Chelonus phthorimaeae 121
Chelonus sp. 79, 81
?*Chelonus* sp. 77
chenopodii, *Liriomyza* 45
Chermes sp. 62
cherries 147, 155, 217
cherryslug 147-152
chestnut 307
chickweed 97
chilensis, *Aphytis* 179, 180
chilensis, *Psecacera* 13
Chilocorus 181
chilonus, *Trichogramma* 116, 117
chinensis, *Pachylister* 389
chinensis, *Turanogonia* 52
chionaspidis, *Arrhenophagus* 180
chironomids – see Chironomidae
Chironomidae 335
chlorideae, *Campoletis* 89, 90
chloromerus, *Torymus* 172, 174
chloropid flies – see Chloropidae
Chloropidae 208, 209, 210
chloropterus, *Thyreocephalus* 10, 39
Choristoneura murinana 81
chou moellier 46, 135, 384
Chromatomyia horticola 46, 47
Chromatomyia syngenesiae 45, 361
chrysanthemum 45, 251
Chryseococcus arecae 313, 314
Chrysocharis horticola 48
Chrysocharis pubicornis 45, 47
Chrysocharis sp. 45, 46, 47

Chrysodeixis argentifera 67, 68, 115
Chrysodeixis eriosoma 53, 67-72, 115, 116, 117, 144
Chrysolina hyperici 310, 354, 355, 356
Chrysolina quadrigemina 354, 355, 356
chrysomphali, *Aphytis* 180
Chrysomyia rufifacies 381, 382, 384
Chrysonotomyia trifolii 77, 78, 79-80, 83, 84
Chrysopa californica 233, 234
Chrysopa nigricornis 60, 62
Chrysopa ramburi 60, 62, 230, 234
Chrysopa sp. 1, sp. 2, sp. 3 60, 61, 62
Chrysopa sp. 4, sp. 5, sp.6 60
Chrysopa spp. 62, 64, 189, 230, 231, 295, 296
Chrysoperla californica 231
Chrysoperla carnea 60, 62, 64
Chrysoperla oculata 60, 61
Chrysoperla plorabunda 60, 61, 231
Chrysophtharta bimaculata 281, 283
chrysopid sp. – see Chrysopidae
Chrysopidae 56, 57, 64, 156, 198, 242, 243
Chrysosoma mobile 171
Cicadellidae 184
cinctellus, *Meteorus* 156
cinctipes, *Schlettererius* 300, 304, 305
cinctus, *Gelis* 156, 157
cineraria 67
cinerea, *Cententer* 11
cinerea, *Eucalyptus* 263
cinnabar moth 362-363, 365
circumscriptus, *Apanteles* 290
circumscriptus group, *Apanteles* 290
Cirsium arvense 309, 341, 343-345
Cirsium palustre 341
Cirsium spp. 340
citri, *Planococcus* 223, 231
citriformis, *Hirsutella* 242
citrina, *Encarsia* 153, 179, 180, 181
citrophilus mealybug 224
citrophilus, *Pseudococcus* 224
citrus 145, 153, 177, 178, 188, 207, 210, 213, 215, 223, 229, 233, 237, 240, 263
citrus red scale 179
clandestinum, *Pennisetum* 17
clausa, *Morphodexia* 13
claviger, *Metaphycus* 153
Cleobora mellyi 281, 282, 283-284, 286
Cleome spp. 129
clianthi, *Liriomyza* 45
Clianthus puniceus 45
clivinoides, *Barypus* 13
clover 19, 29, 39, 44, 97, 143
clover seed crops 43
clover springtail 29
clover weevil 97
Cnemalobus gayi 13
Cnephasia jactatana 191
Coccidae 207, 226
Coccidoctonus dubius 238, 239
Coccinella californica 58
Coccinella leonina 56, 57
Coccinella repanda 60, 61
Coccinella septempunctata 59, 60, 64
Coccinella transversoguttata 59, 60
Coccinella undecimpunctata xii, 3, 27, 33, 43, 57-58, 60, 63, 64, 105, 145, 208
coccinellae, *Dinocampus* 27, 57, 59, 61, 63, 64, 208
coccinellae, *Perilitus* 27
coccinellid – see Coccinellidae
Coccinellidae 56, 57, 64, 88, 171, 218, 246, 295
Coccoidea 237
Coccophagus gurneyi 228, 230, 231, 232, 233, 234
Coccophagus ochraceus 237
Coccophagus scutellaris 153
Coccophagus n. sp. 230
Coccophagus spp. 227, 230
coccophthora, *Creobota* 265
Coccus hesperidum 153-154, 239
codling moth 155, 161-169, 187, 192, 201, 217, 218
Coelomycidium sp. 375
coelopae, *Antarctopria* 381, 384
coffeae, *Saissetia* 239
colensonis, *Austroletes* 171
Coleophora albicosta 368
Coleophora alcyonipennella 74, 76
Coleophora deauratella 74, 75, 76, 79, 82, 83
Coleophora frischella 73-85
Coleophora paripennella 75
Coleophora spissicornis 73-85
Coleophora trifolii 74, 75, 76, 77, 78, 80
Coleophora spp. xii, 44, 73-85
Coleoptera 60, 157
collaris, *Diadromus* 44, 138-139, 140
collaris, *Macrocentrus* 52
collaris, *Thyraeella* 138-139
Collembola 29
collyerae, *Apterygothrips* 218
colonica, *Aoteapsyche* 375
Colpoclypeus florus 193
comfrey 69
common house fly 387
common wasp 373, 395-399
communis, *Pyrus* 217
comparatus, *Rhagigaster* 12
Comperiella bifasciata 181
complanatus, *Laemostenus* 156
complanatus, *Pristonychus* 156
complanatus, *Trioxys* 34, 35, 36
composites 87
Compsilura concinnata 129, 130, 131
Comstock's mealybug 224
comstocki, *Pseudococcus* 223, 224
comta, *Bonnetia* 52
comta, *Linnaemyia* 52, 53
concinnata, *Compsilura* 129, 130, 131
conformis, *Harmonia* 58, 60, 63, 64
confractor, *Metasyrphus* 61, 63
congruens, *Rhinotorus* 148, 149, 150
conicus, *Rhinocyllus* 309, 340, 341, 343
Conidiobolus obscurus 4, 105
coniothyrium, *Leptosphaeria* 357
Conoderus exsul 10
Conoderus spp. 17

Contarinia pyrivora 171, 172
contractus, *Chelonus* 77, 79, 82, 84
sp. nr. *contractus*, *Chelonus* 79
convergens, *Hippodamia* 58, 60, 64
Conwentzia psociformis 61, 63
Copidosoma bakeri 70
Copidosoma desantisi 121
Copidosoma floridanum 68, 69, 70, 71
Copidosoma koehleri 121, 122, 123, 124
Copidosoma truncatellum 69
Copidosoma uruguayensis 124
Copidosoma sp. 68, 123
Copris incertus 389
Coraebus rubi 358
Corcyra cephalonica 116
Cordyline sp. 192
coriaceus, *Eriococcus* 153, 179, 229, 255, 263-266
Coriaria arborea 241
corn 51, 111
cornigerum, *Eusemion* 153
cornuarietis, *Marisa* 333
Coronopus sp. 97
corpulenta, *Drosicha* 207
cosmopolitan armyworm 107-109
costalis, *Tongyus* 226
Costelytra 18
Costelytra zealandica x, xii, 1, 9-16, 18, 20, 24, 40
costelytrae, *Nosema* 10
costirostris, *Listroderes* 97
Cotesia glomeratus 129
Cotesia kazak 89
Cotesia plutellae 139
Cotesia ruficrus 52, 68, 107
cotidianus, *Gobiomorphus* 335
cotton 87, 143
  wild 62
cottony cushion scale xii, 145, 207-211
couch grass 101
crassipes, *Eichhornia* 325
crataegi, *Edwardsiana* 183-186
crawfordi, *Ophelosia* 234
creeping thistle 343
Creobota coccophthora 265
crevieri, *Rhyssa* 300, 304, 305
croceipes, *Glabromicroplitis* 89, 90
croceipes, *Microplitis* 89
cruciferous crops 55, 57, 135, 136, 139
Cryptochetum iceryae 208, 209, 210
cryptoides, *Neozeleboria* 12
Cryptolaemus montrouzieri 145, 228-229, 230, 231, 233, 263, 264, 265
Cryptolaemus sp. 232
cryptophagid – see Cryptophagidae
Cryptophagidae 347
Cryptoscenea australiensis 227, 234
Cryptus sexannulatus 164, 166
Ctenichneumon panzeri 52, 53
Ctenochares bicolorus 68
Ctenopeustis obliquana 157, 187, 191
Ctenopharyngodon idella 323, 333, 334-335, 336
Ctenopharyngodon idella, triploid 336
Ctenoplusia albostriata 67, 115, 116
cucumbers 251
cucumeris, *Amblyseius* 246
cucumeris, *Neoseiulus* 218
cuprea, *Potosia* 18
Cupressus macrocarpa 213
currant 217
currant clearwing 201
curvimaculatus, *Chelonus* 121, 123
curvimaculatus, *Microchelonus* 121, 123
cut worms 124
cyanea, *Anacystis* 321
cyanea, *Scutellista* 239
cyanella, *Lema* 343, 344
Cyanophyceae 321
Cycloneda munda 58, 60
Cycloneda sanguinea 58
Cydia internana 368
Cydia molesta 155-159, 161, 192
Cydia pomonella 115, 155, 157, 161-169, 201, 217
Cydia succedana 368
Cydia spp. 161
Cygnus atratus 333
Cyphomandra betacea 119, 251
cyprinacea, *Lernaea* 334
Cyprinus carpio 333, 334
Cytisus scoparius 310, 347-349
cytoplasmic polyhedrosis virus 116

Dacnusa areolaris 45
dactylopii, *Ophelosia* 225, 226
Dactylopius adonidum 224
Dactylopius arecae 313
dahlias 201
Dalaca pallens 40
Dalaca variabilis 40
dalmani, *Habrolepis* 258
dalmanii, *Habrolepis* 258
dalmanni, *Habrolepis* 258, 259, 260
dalmanni, *Hemisarcoptes* 259
Danaus plexippus 115
Dasineura mali 171-175
Dasineura plicatrix 358
Dasineura pyri 171-175
Dasineura sp. 368
Dasypoda selenophora 115
Dasypolia templi 202
Dasyuromyia inornata 13
Dasyuromyia sarcophagidea 13
Dasyuromyia sternalis 13
Dasyuromyia tarsalis 13
Dasyuromyia sp. 13
deauratella, *Coleophora* 74, 75, 76, 79, 82, 83
decepta, *Degithina* 39
deciduous tree crops 178
decurrens, *Acacia* 231
Degithina decepta 39
Deladenus siricidicola 255, 299
delaiguei, *Listroderes* 97, 98, 99
demades, *Platygaster* 172, 173, 174
demades, *Prosactogaster* 172
demersum, *Ceratophyllum* 332, 333
demeter, *Apanteles* 188, 189

demolitor, *Microgaster* 90
Dendrocerus aphidium 35
Dendrocerus carpenteri 6
Dendrocerus niger 56
Dendrocerus sp. 106
dendrolimi, *Trichogramma* 116, 117
densa, *Beauveria* 116
densa, *Egeria* 331, 332, 335
denticornis, *Cerodontha* 45
Deroceras reticulatum 156
desantisi, *Copidosoma* 121
despecta, *Wiseana* 39
destructor, *Mayetiola* 43, 101-104
Dexia uniseta 19
Diadegma eucerophaga 138
Diadegma fenestralis 136, 137-138, 140
Diadegma majalis 77, 80
Diadegma molliplum 123, 124
Diadegma raoi 124
Diadegma semiclausum 44, 125, 136, 137, 138, 139, 140
Diadegma stellenboschense 123
Diadegma surandrai 124
Diadegma turcator 122, 124
Diadegma spp. 77, 80, 136, 137, 190
Diadiplosis koebelei 228
Diadromus collaris 44, 138-139, 140
Diadromus subtilicornis 139
Diadromus sp. 136
Diaeretiella rapae 56
diamondback moth xii, 125, 135-142
diapriid – see Diapriidae
Diapriidae 172
Diaspididae 177-182
diaspidis, *Aphytis* 179, 180, 181
Diastrophus nebulosus 358
Diastrophus rubi 358
Dibrachys boarmiae 398
Dibrachys cavus 204
Dibrachys vesparum 398
Dictyonota strichnocera 368, 369
didymator, *Hyposoter* 88, 89
difficilis, *Listroderes* 97-99
Digitalis purpurea 309, 351-352
Diglyphus isaea 45, 46, 48
Diglyphus minoeus 46
Diglyphus sp. nr. *chabrias* 46
Diglyphus spp. 46, 47, 48
Digonochaeta spinipennis 202
dilatata, *Paropsis* 281
dilatatum, *Paspalum* 17
dimidiata, *Elaphroptera* 11
dimidiata, *Harmonia* 59, 60, 64
diminutus, *Balanococcus* 223, 224
Dinocampus coccinellae 27, 57, 59, 61, 63, 64, 208
Dinotiscus eupterus 272-273
Diomus pumilio 296
Diomus sp. 230
Diphyus gradatorius 107
Diplason laetatorius 57
Diplococcus sp. 112
Diplosis sp. 228, 230
dipsaci, *Ditylenchus* 368
Diptera 61
dirhodum, *Metopolophium* 43, 44, 105-106
discoideus, *Sitona* 1, 2, 25, 27-28
Disonycha argentinensis 326-327, 328-329
dispar, *Rhizophagus* 272
distachyus, *Aponogeton* 332
Ditylenchus dipsaci 368
dog fly 387
Dolichovespula saxonica 395, 397, 398
domestica, *Musca* 382, 387, 388, 392
Douglas fir 271, 277
Douglas fir seed chalcid 277-279
dragonflies 373
Dreyfusia nordmannianae 297
Drepanacra binocula 197
Drosicha corpulenta 207
Drosophilidae 387
dryinid – see Dryinidae
Dryinidae 184, 185, 242
dubius, *Coccidoctonus* 238, 239
dubius, *Quaylea* 239

eadyi, *Aphidius* 4, 5, 6
earthworms 18, 74
earwigs 163, 193, 201
Echthromorpha intricatoria 68, 87, 107, 115, 188
Ecphoropsis perdistinctus 89
edulis, *Passiflora* 241
Edwardsiana crataegi 183-186
efferata, *Pales* 51, 53
Egeria densa 331, 332, 335
egg plant 119
Eichhornia crassipes 325
Eirone rufopicta 12
Elachertus sp. 188
Elaphroptera dimidiata 11
Elcar 116
eleven-spotted ladybird 57-58
Elis sp. 13
elm 217
elmoi, *Parascaptomyza* 46
elmoi, *Scaptomyza* 46, 48
Elodea canadensis 331, 332
Elsinoe veneta 357
emarginatoria, *Megarhyssa* 300, 304
Empis otakauensis 375
Empoasca australis 183
Enarmonia pomonella 161
Enaysma splendens 290
Encarsia citrina 153, 179, 180, 181
Encarsia formosa 145, 251-252
Encarsia pergandiella 251
Encarsia pergandiella prob. 251
Encarsia perniciosi 179, 180, 181
Encyrtidae 226
Encyrtus lecaniorum 237
endius, *Spalangia* 388, 389, 390, 391, 392
English oak 257, 258
Enicospilis insularis 51
Enoggera nassaui 282, 285, 286
Enoggera sp. 286
ensiger, *Ibalia* 303
entomophila, *Serratia* 10, 14

Entomophthora 56
Entomophthora planchoniana 4, 34, 105
Entomophthora sphaerosperma 129
Entomophthora sp. 189
entomopox virus 40
Epalxiphora axenana 191
Ephedrus plagiator 5, 6
Ephialtes brevicornis 81
Ephialtes caudatus 164
Ephialtes messor 164, 257
epigonus, *Pediobius* 102, 103
Epiphyas postvittana xii, 155, 156, 157, 166, 187-195, 201
Epiplagiops littoralis 98
Episinus sp. 184
Episyrphus ?balteatus 61, 63
Epitetracnemus zetterstedtii 180
Eriborus trochanterus 122, 124
Ericydnus sp. 384
Eridolius rufonotatus 148
Erigeron spp. 67
Erinaceus europaeus 93
Eriococcidae 263
Eriococcus 237
Eriococcus coriaceus 153, 179, 229, 255, 263-266
Eriococcus eucalypti 263
Eriococcus orariensis 310
Eriococcus spp. 263
Eriosoma lanigerum xii, 145, 197-199
eriosoma, *Chrysodeixis* 53, 67-72, 115, 116, 117, 144
ervi, *Aphidius* 4, 5, 6, 7, 105
Erynia kondoiensis 4
Erynia neoaphidis 4
erythrophthalmus, *Scardinius* 333
essigi, *Acalitus* 357
eucalypti, *Eriococcus* 263
Eucalyptus cinerea 263
Eucalyptus globulus 263, 267, 281
Eucalyptus gunnii 263
Eucalyptus linearis 267
Eucalyptus macarthuri 263
Eucalyptus nitens 281
Eucalyptus obliqua 263
Eucalyptus ovata 283
Eucalyptus pulchella 267
Eucalyptus radiata 283
Eucalyptus regnans 263
Eucalyptus viminalis 263, 267, 281
Eucalyptus spp. xi, xii, 255, 263, 264, 265, 267, 281, 284, 286
eucalyptus tortoise beetle 281-287
Eucelatoria armigera 88, 89
Eucelatoria illota 89
eucerophaga, *Diadegma* 138
?eucerus, *Habrocytus* sp. 82
eugeniae, *Phenacaspis* 177
eugeniae, *Pseudaulacaspis* 177, 178, 180
Euglandina spp. 94
eumenid – see Eumenidae
Eumenidae 190
eupatorii, *Cercospora* 318, 319
Eupelmus messene 101
euphorbiae, *Macrosiphum* 55, 353
Eupithecia pulchellata 351
Eupithecia pyreneata 351
Euplectrus sp. 107, 108
euproctidis, *Trichogramma* 116, 117
Eupteromalus sp. 132, 137
eupterus, *Dinotiscus* 272-273
europaea, *Microphthalma* 11, 18, 19, 20
europaeus, *Erinaceus* 93
europaeus, *Ulex* 309, 367-371
European earwig 193, 201-205
European red mite 165, 217-221
Eurytoma sp. 77, 80
Eusemion cornigerum 153
Eutorna phaulacosoma 357
Euxanthellus philippiae 153, 237
evanescens, *Trichogramma* 116, 117
evergreen laurel 181
evergreen oak 289
evonymellae, *Tetrastichus* 347, 348
excavatus, *Phyllognathus* 18
excelsa, *Lissopimpla* 39, 88, 107, 188
excessana, *Planotortrix* 157, 187
Exochomus nigromaculatus 232
Exochus sp. 190
exsul, *Conoderus* 10

Fagus spp. 289
fagus, *Scymnus* 179
falcatalis, *Platyptilia* 191
falcifer, *Rhizoecus* 223
fallacis, *Amblyseius* 219, 247
fallacis, *Neoseiulus* 219, 246, 247-248
Fannia albitarsis 392
Fannia canicularis 387, 392, 393
Fannia spp. 388
farinaria, *Patagoniodes* 361
fasciata, *Phanerotoma* 164, 166
fasciatum, *Melanostoma* 3, 33, 57, 105, 227
faurei, *Haplothrips* 218
feijoa 155
Feijoa sellowiana 155
Feijoa sp. 289
feltiae, *Microplitis* 53
feltiae, *Steinernema* 214
fence posts 63
fenestralis, *Angitia* 137
fenestralis, *Diadegma* 136, 137-138, 140
fennel 11, 19
feredayi, *Pales* 68
feredayi, *?Pales* 188
ferrugineus, *Rhizophagus* 272
ferus, *Subprionomitus* 226
field crops xi, 43, 115, 245
field cutworm 52
Fiordland crested penguins 375
fir 271, 297
fish 309
flavella, *Signiphora* 179, 180
flavus, *Aphelinus* 307
flavus, *Aspergillus* 327
flavus, *Metaphycus* 154
flavus, *Microterys* 153, 239
Flock House virus 10

floridanum, *Copidosoma* 68, 69, 70, 71
florus, *Colpoclypeus* 193
flos-aquae, *Anabaena* 321
flower crops 93
flowering cherry 155
flowers 201
fluitans, *Glyceria* 332
flystrike 373, 381, 383, 384
fodder crops 9
Foeniculum vulgare 11
forage brassicas 43
forage oats 105
forest xi
forest plantings 187
forestieri, *Platyomus* 237
forestieri, *Rhyzobius* 237, 238, 264
forestieri, *Scymnodes* 237
Forficula auricularia 163, 189, 201-205
formicarius, *Thanasimus* 272, 273
formosa, *Encarsia* 145, 251-252
foveatus, *Listroderes* 97
foxglove 309, 351-352
fragiferum, *Trifolium* 73
fragilis, *Pseudococcus* 224
frenata, *Micraspis* 58, 60
frischella, *Coleophora* 73-85
froggatti, *Phylacteophaga* 255
froggatti, *Typhlocyba* 183-186
Froggattimyia lasiophthalma 267
Froggattimyia tillyardi 282
Froggattimyia spp. 282
Froggatts apple leafhopper 183-186
fructicola, *Sclerotinia* 155
fruit xi
  berryfruit 145, 146, 178, 187, 245, 246, 247, 248, 357, 359
  pipfruit 158, 161, 177, 178
  pomefruit 145, 146, 187, 217
  stonefruit 55, 146, 155, 201, 202, 217
  summerfruit 55, 155, 158, 177, 178, 201
fruit crops 187
fruit trees 223, 237, 245
fruticosus, *Rubus* 309
fruticosus agg., *Rubus* 357-360
fulica, *Achatina* 93
sp. nr. *fuliginosus*, *Xyaloplothrips* 218
?*fumoso-roseus*, *Paecilomyces* 74
funesta, *Pales* 188
fungi 10, 17, 163, 202, 204, 242
funiculatum, *Trichogramma* (*Trichogrammanza*) 67, 68, 115, 188
Fusarium lateritum 178
Fusarium sp. 74
fusca, *Ithone* 11, 13
fuscirostre, *Apion* 348
fuscitarsus, *Scaptomyza* 48
fusciventris, *Anagyrus* 233, 234

gahani, *Pseudococcus* 224, 230
gaidnerii, *Salmo* 335
Galleria mellonella 116
gallicella, *Scythris* 368
gamasid mite 217
Gambrus stokesii 157, 166, 192
garden plants 243
gardens 115, 343
gastropods 335
gayi, *Cnemalobus* 13
gelechiae, *Bracon* 121, 122, 124
gelechiae, *Microbracon* 121
Gelis areator 77, 81
Gelis cinctus 156, 157
Gelis tenellus 156, 157
Gelis tonsus 77, 81
Gelis sp. ?*areator* 77
Gelis spp. 156, 189
Genista hispanica 369
Genista tinctoria 369
genistae, *Aceria* 369
geranium 67
German wasp 241, 281, 375, 395-399
germanica, *Vespula* 113, 241, 281, 375, 382, 395-99
giant African snail 93
giardi, *Zeuxidiplosis* 354, 356
Gibberella baccata 178
Glabridorsum stokesii 156, 157, 158, 166, 190, 191, 192, 193
Glabromicroplitis croceipes 89, 90
glaseri, *Steinernema* 11, 14, 41
Glaucias amyoti 147
globulus, *Eucalyptus* 263, 267, 281
glomeratus, *Apanteles* 129, 130, 131, 132
glomeratus, *Cotesia* 129
glow-worm 94
Glyceria fluitans 332
Glyceria maxima 332
Glypta rufiscutellaris 158
Glypta sp. 190
Gnorimoschema absoluta 119
Gnorimoschema operculella 119
Gnorimoschema plaesiosema 119
Gobiomorphus cotidianus 335
golden haired bark beetle 271-275
golden oak scale 257
Gonaxis quadrilateralis 93, 94
Gonioctena olivacea 348
Goniozus sp. ?*antipodum* 191
Goniozus sp. 188, 190, 191
Gonipterus scutellatus 255, 267-269
gooseberry 217
gorse 19, 226, 309, 358, 367-371
gowkongensis, *Bothriocephalus* 334
gracilis, *Thynnoides* 12
gradatorius, *Diphyus* 107
grain crops 107, 108
graminaceous crops 107-109
graminaceous seed crops 115
graminicola, *Phenacoccus* 223, 224, 225
graminosus, *Phenacoccus* 224
graminum, *Scaptomyza* 46
grandipennis, *Scythris* 368
granulosis virus 40, 120, 121, 122, 129, 131, 135, 167
grapes 145, 217, 223, 395
grapevine 213, 215, 223, 227, 228
Graphania mutans 115, 116
Graphania ustistriga 115, 116

Graphognathus leucoloma 1, 13
Grapholita molesta 155, 161
Grapholita pomonella 161
Grapholitha molesta 155
Grapholitha pomonella 161
grass grub x, xii, 1, 24
grass mealybug 224
grasses 23, 45, 47, 56, 105, 115, 223
grasslands 1, 9-16, 102, 347
greasy cutworm 51-54
greedy scale 177, 178, 179, 181
green fly 55
green looper 67-72
green vegetable bug 111-114
greenhouse crops 153, 223, 245
greenhouses 246, 248, 251
gregarines 10, 189, 204
grisella, *Achroia* 115
ground beetles 202, 204
ground cover 247
Gueriniella serratulae 207
Guiglia schauinslandi 299
gum tree scale 255, 263-266
gum tree weevil 267-269
gunnii, *Eucalyptus* 263
gurneyi, *Coccophagus* 228, 230, 231, 232, 233, 234
guttatus, *Mimulus* 332
GV – see granulosis virus
Gyranusoidea advena 226, 233

Habrocytus milleri 82
Habrocytus sp. ?*eucerus* 82
Habrolepis dalmani 258
Habrolepis dalmanii 258
Habrolepis dalmanni 258, 259, 260
Hakea 10
Haplothrips faurei 218
Haplothrips kurdjumovi 218
Harmonia conformis 58, 60, 63, 64
Harmonia dimidiata 59, 60, 64
Harmonia sp. 156, 232
harti, *Hyaliodes* 165, 218, 246
harvestmen 57, 246
hawthorn 183
haywardi, *Campoplex* 122, 123, 124
heath fritillary 351
hedgehog 93, 94, 204, 281
Heirodons atychioides 191
helichrysi, *Brachycaudatus* 361
Helicoverpa armigera 44, 70, 87-91, 115, 116, 117, 144
Helicoverpa armigera conferta 87
Helicoverpa polyhedrosis virus 116
Helicoverpa spp. 89, 90
heliopa, *Scrobipalpa* 119
heliothidis, *Heterorhabditis* 30, 41, 214, 215
Heliothis virescens 88
Heliothis spp. 87, 88, 90
Helix aspersa 93-95
helvolus, *Metaphycus* 239
Hemerobiidae 56, 156, 246, 295
Hemerobius stigma 296
Hemiberlesia lataniae 177, 178, 180
Hemiberlesia rapax 177, 178, 180
Hemiptarsenus semialbiclavus 45, 47
Hemiptarsenus sp. 45
Hemisarcoptes dalmanni 259
Hemisarcoptes malus 181
Hemisarcoptes spp. 181, 258
Hemiteles areator 81
Hemiteles sp. 1 156
Heracleum sphondylium 202
herbaceous plants 57
hesperidum, *Coccus* 153-154, 239
hessian fly 101-104
Heterocrossa sp. 357
Heteronychus arator 1, 11, 14, 17-21
Heteronyx spp. 10
Heteropsyche melanochroma 242
Heteropsyche sp. 242
Heterorhabditis bacteriophora 11, 12
Heterorhabditis heliothidis 30, 41, 214, 215
Heterorhabditis sp. 14
Heterospilus spp. 23, 24, 25
Hexamera alcis 39
Hexomyza spp. 45
hiemalis, *Platygaster* 101, 102, 103
hill country 347
hilli, *Calliphora* 381
Hippodamia convergens 58, 60, 64
Hirsutella citriformis 242
Hirsutella versicolor prob. 242
Hirsutusporos austrosimulii 375
hirta, *Oemona* 145, 213-216, 368
hispanica, *Genista* 369
hogcress 97
hogweed 202
hollyhock 201
hop aphids 201
Horogenes sp. 77, 81
horridus, *Ceuthorhynchidius* 340
horridus, *Trichosirocalus* 340, 341
horticola, *Chromatomyia* 46, 47
horticola, *Chrysocharis* 48
horticola, *Stathmopoda* 191
horticultural crops 9, 224, 234
hortona, *Xenocalliphora* 381
house fly 373
house plants 153
hudsoni, *Aspicolpus* 213
humilis, *Polistes* 147
Hungariella brounii 225
Hungariella peregrina 225
Hungariella ?*pretiosa* 25
hutiwai 313
Hyaliodes harti 165, 218, 246
Hybopygia varia 384, 385, 388
hybridum, *Trifolium* 73
Hydrilla verticillata 332
Hydrobiosis parumbripennis 375
hygrophila, *Agasicles* 325, 326, 328, 329
Hylastes ater 255, 271-275
Hylurgops palliatus 274
Hylurgus ligniperda 271-275
Hymenostilbe spp. 74, 242
Hyperecteina aldrichi 11
hyperici, *Chrysolina* 310, 354, 355, 356

Hypericum perforatum 309, 310, 353-356
Hypericum sp. 177
hyperodae, *Microtonus* 23, 24, 25
Hypophthalmicthys molitrix 322, 323
Hyposoter didymator 88, 89

Ibalia ensiger 303
Ibalia leucospoides 303
Ibalia leucospoides ensiger 300, 301, 303, 305
Ibalia leucospoides leucospoides 299, 300, 301, 302, 303, 304, 305
Iceland poppies 97
Icerya aegyptiaca 207
Icerya montserratensis 207
Icerya palmeri 207
Icerya purchasi viii, xii, 207-211, 263, 368
Icerya seychellarum 207
Icerya spp. 207, 231
iceryae, *Cryptochetum* 208, 209, 210
iceryae, *Rodolia* 209
Ichneumon lotatorius 39
Ichneumon promissorius 87, 107, 115
ichneumonid, ichneumonid sp., ichneumonids – see Ichneumonidae
Ichneumonidae 1, 2, 3, 88, 89, 188, 190
Idatiella albisignata 162, 218
idella, *Ctenopharyngodon* 323, 333, 334-335, 336
idella triploid, *Ctenopharyngodon* 336
Idiatella albisignita 184
ilex, *Quercus* 290
illota, *Carcelia* 88, 89
illota, *Eucelatoria* 89
imported cabbage worm 129
incertus, *Copris* 389
indica, *Rosa* 358
inermis, *Austroaeschna* 376
infuscata, *Alloxysta* 106
inornata, *Dasyuromyia* 13
Inostemma boscii 172, 174
Inostemma piricola 171, 172
insectifurax, *Neopolycystus* 282, 285
insularis, *Enicospilis* 51
internana, *Cydia* 368
intricatoria, *Echthromorpha* 68, 87, 107, 115, 188
ipsilon, *Agrotis* 51-54, 69, 107, 115, 116, 144
ipsilon aneituma, *Agrotis* 51
iridescent virus 10
isaea, *Diglyphus* 45, 46, 48
Ischnus stokesii 157, 166, 192
Isocheta aldrichi 11
Itamus varius 9
Ithone fusca 11, 13
itiiti, *Microsporidium* 24
Itoplectis maculator 77, 81
ivelae, *Trichogramma* 90
Ixeuticus martius 162

jacobaea, *Senecio* 45, 309, 361-366
jacobaeae, *Botanophila* 363-364
jacobaeae, *Longitarsus* 364-365
jacobaeae, *Pegohylemyia* 363
jacobaeae, *Tyria* 362-363
jactatana, *Cnephasia* 191
Japanese beetle 10
japonica, *Popillia* 10
Juncus articulatus 332
Juncus spp. 325

kaka beak 45
kale 43, 129
kazak, *Apanteles* 88, 89, 90
kazak, *Cotesia* 89
Kermaphis pini var. *laevis* 295
kinbergii, *Nabis* 88
kiwifruit 146, 177, 178, 179, 181, 189, 241, 247
koebelei, *Diadiplosis* 228
koehleri, *Copidosoma* 121, 122, 123, 124
kondoi, *Acyrthosiphon* 1, 2, 3-7, 33, 84
kondoiensis, *Erynia* 4
kowhai 63
Kuhneola uredinis 357
kumara 17, 143
kurdjumovi, *Haplothrips* 218

lacewings 156
ladybirds 105
Laemostenus complanatus 156
laetatorius, *Diplason* 57
laeviceps, *Thynnoides* 12
laevis, *Pineus* 255, 295-297
laeviventris, *Meteorus* 53
Lagarosiphon major 331, 332
lambinus, *Zaomma* 180
Lampyris noctiluca 94
lanigera, *Aphis* 197
lanigera, *Schizoneura* 197
lanigerum, *Eriosoma* xii, 145, 197-199
Lantana sp. 120
lapidaria, *Bdellodes* 29, 30, 31
lapidarius, *Biscirus* 29
larch 271, 299
Larix spp. 271
lasiophthalma, *Frogattimyia* 267
Lasioptera rubi 358
Laspeyresia pomonella 161
latania scale 177, 178
lataniae, *Hemiberlesia* 177, 178, 180
lateralis, *Zosterops* 57, 156, 162, 163
lateritum, *Fusarium* 178
Lathrolestes luteolator 148, 149, 150, 151
laticorne, *Austrosimulium* 376
latifrons, *Trichoprosopus* 13
latrobei, *Australoglypta* 190
laxa, *Palexorista* 88, 89
leaf curl 55
leafminers 45-49
leafrollers 146, 187
lecanii, *Verticillium* 56, 251
lecaniorum, *Encyrtus* 237
Lecanium spp. 237
legume seed crops 87
legumes 67, 87, 143
Leis sp. 232
Lema cyanella 343, 344
lemon 226
lemon tree borer 145, 213-216

lentils 3
leonina, *Coccinella* 56, 57
Lepidoptera 18, 112, 157
Lepidosaphes ulmi 177, 178, 180
lepidus, *Orgilus* 121, 122, 123, 124
Leptomastidea abnormis 231
Leptomastix abnormis 232
Leptospermum 10
Leptospermum scoparium 310
Leptospermum sp. 19
Leptosphaeria coniothyrium 357
Lernaea cyprinacea 334
lesser house fly 387
lestophonus flies 208
lettuce 201
Leucocytozoon tawaki 375
leucoloma, *Graphognathus* 1, 13
Leucopis nigricornis 61, 63
Leucopis obscura 61, 63, 296
Leucopis puncticornis 61, 63
Leucopis tapiae 295-296, 297
Leucopis sp. 295, 296
Leucoptera spartifoliella 347, 348
leucospoides ensiger, *Ibalia* 300, 301, 302, 303, 305
leucospoides, *Ibalia* 303
leucospoides leucospoides, *Ibalia* 299, 300, 301, 303, 304, 305
lightbrown apple moth 155, 187-195, 201
ligniperda, *Hylurgus* 271-275
linearis, *Eucalyptus* 267
lineolata, *Rhyssa* 299
Linnaemyia comta 52, 53
lintearius, *Tetranychus* 368, 369-370
Liotryphon caudatus 157, 164, 165-166, 167
Liparetrus spp. 10
Liquidambar spp. 289
Liriomyza brassicae 45, 46, 47, 48
Liriomyza chenopodii 45
Liriomyza clianthi 45
Liriomyza trifolii 48
Liriomyza spp. 45
Lissopimpla excelsa 39, 88, 107, 188
Listroderes costirostris 97
Listroderes delaiguei 97, 98, 99
Listroderes difficilis 97-99
Listroderes foveatus 97
Listroderes obliquus 97
Listronotus bonariensis 1, 23-26
Litomastix maculata 68, 69
Litomastix truncatellum 69
Litomastix sp. 68
littoralis, *Epiplagiops* 98
litura, *Ceutorhynchus* 343, 344
litura, *Spodoptera* 143-144
loewi, *Scymnus* 228
loganberry 358, 359
longicorne, *Austrosimulium* 376
longicornis, *Plagiomyia* 51, 53
longisetus, *Agistemus* 218
longispinosus, *Amblyseius* 246
longispinus, *Pseudococcus* 223, 224, 225, 227, 228, 231, 232, 233, 234
Longitarsus jacobaeae 364-365
longtailed mealybug 224
Lophocheilus anilitatis 12, 14
lotatorius, *Ichneumon* 39
Lotus spp. 3
lounsburyi, *Metaphycus* 238
lucerne 1, 3, 4, 7, 27, 28, 29, 33, 35, 39, 56, 63, 88
lucerne aphid 56, 201
lucerne flea 29-32
Lucilia sericata 381, 382, 383, 384
Ludwigia spp. 332
lugubris, *Thynnoides* 12
luteolator, *Lathrolestes* 148, 149, 150, 151

macadamia 111
macarthuri, *Eucalyptus* 263
macrocarpa, *Cupressus* 213
Macrocentrus ancylivorus 155, 158
Macrocentrus collaris 52
Macrocentrus rubromaculatus 51, 52, 107, 115
Macroneura vesicularis 101, 102, 103
macropilis, *Phytoseiulus* 247
Macropiper spp. 213
Macrosiphum euphorbiae 55, 353
maculata, *Litomastix* 68, 69
maculator, *Itoplectis* 77, 81
maculicoxis, *Pseudorhyssa* 304
maculipennis, *Plutella* 135
maidis, *Trichogramma* 116
maize 17, 43, 44, 51, 52, 70, 108
majalis, *Diadegma* 80
major, *Lagarosiphon* 331, 332
majus, *Tropaeolum* 48
mali, *Aphelinus* 145, 198
mali, *Dasineura* 171-175
mali, *Planococcus* 223, 226, 234
malicorticis, *Pezicula* 197
malloi, *Vogtia* 325, 326, 327, 329
mallow 97
Malus sylvestris 289
malus, *Hemisarcoptes* 181
mammals 10
Manduca quinquemaculata 131
manducator, *Alysia* 382, 383, 385
manuka 19, 310
maoricus, *Nabis* 57
marchali, *Misocyclops* 172
marginata, *Pennisetia* 358
marginiventris, *Apanteles* 90
marianum, *Silybum* 310
Marisa cornuarietis 333
maritimus, *Pseudococcus* 224, 233, 234
martius, *Ixeuticus* 162
Mastrus carpocapsae 164, 166
Mattesia sp. 10
mauritianum, *Solanum* 213
mauve pittosporum scale 177, 178, 179
maxima, *Glyceria* 332
Mayetiola destructor 43, 101-104
mealybugs 223-236, 237, 264
Mecodema spp. 17
Medicago sativa 1, 3, 33
Medicago spp. 27, 33
medics 27

Megarhyssa emarginatoria 300, 304
Megarhyssa nortoni 303
Megarhyssa nortoni nortoni 300, 301, 304
Megarhyssa praecellens 300, 304, 305
Megastigmus spermotrophus 255, 277-279
Megastigmus sp. 318, 319
Melampyrum spp. 351
Melanagromyza senecionella 45, 361
Melangyna novaezealandiae 57, 105
melanochra, *Stathmopoda* 264
melanochroma, *Heteropsyche* 242
Melanogromyza spp. 45
Melanostoma fasciatum 3, 33, 57, 105, 227
Melilotus altissima 75
Melilotus sp. 74
Melittobia acasta 398
Melittobia chalybii 396
Mellicta athalia 351
mellonella, *Galleria* 116
mellyi, *Cleobora* 281, 282, 283-284, 286
Melolonthinae 11, 14, 17, 40
menziesii, *Pseudotsuga* 271, 277
merceti, *Signiphora* 179, 180
Mermis subnigrescens 204
Mermis sp. 9
merula, *Turdus* 93
Mesidiopsis 307
mesnili, *Nosema* 129
Mesochorus sp. 283
Mesoleius caninae 149
Mesoleuca albicillata 358
Mesopolobus spermotrophus 277, 278
Mesostenus albopictus 213
mesotaenia, *Catoblemma* 265
messaniella, *Phyllonorycter* 255, 289-293
messene, *Eupelmus* 101
messor, *Calliephialtes* 164
messor, *Ephialtes* 164, 257
Metaglymma spp. 17
Metaphycus asterolecanii 258, 259
Metaphycus claviger 153
Metaphycus flavus 154
Metaphycus helvolus 239
Metaphycus lounsburyi 238
Metarhizium anisopliae 40, 41, 116
Metaseiulus occidentalis 219, 246, 248
Metasyrphus confractor 61, 63
Metatetranychus ulmi 217
Meteorus cinctellus 156
Meteorus laeviventris 53
Meteorus sp. 190, 282
Metoecus paradoxicus 396, 398
Metopolophium dirhodum 43, 44, 105-106
Mexican devil weed 309, 317-320
mice 93
michiganensis, *Microphthalma* 11, 13
Micraspis frenata 58, 60
Microbracon gelechiae 121
Microchelonus curvimaculatus 121, 123
Microchelonus phthorimaeae 121
Microctonus aethiopoides 25, 27, 28
Microctonus hyperodae 23, 24, 25
Microcystis aeruginosa 321
Microcystis sp. 322, 323
Microgaster demolitor 90
Microgaster spp. 68, 90
Micromeriella atropos 19
Micromus tasmaniae 3, 4, 6, 33, 57, 64, 88, 105, 197, 227
Microphanurus sp. 111
Microphthalma capensis 18
Microphthalma europaea 11, 18, 19, 20
Microphthalma michiganensis 11, 13
Microphthalma sp. 18
microphylla, *Rorippa* 332
Microplitis croceipes 89
Microplitis feltiae 53
Microplitis sp. 68
microsporidian 51, 52, 74, 116
Microsporidium itiiti 24
Microsystis sp. 321
Microterys flavus 153, 239
mignonette 12
milky disease 10
milleri, *Habrocytus* 82
milleri, *Sarcophaga* 384
Mimulus guttatus 332
minax, *Trite* 156
minoeus, *Diglyphus* 46
mint 69
minus, *Asterodiaspis* 257, 258
?*minutum*, *Trichogramma* 162
mira, *Alamella* 226
Miridae 88, 185, 218, 246, 249
mirids – see Miridae
miscanthi, *Sitobion* 55, 56
Misocyclops marchali 172
Misocyclops ornatus 172
Misocyclops sp. 172
mites 201, 258, 347
mobile, *Chrysosoma* 171
mobilus, *Psilopus* 171
molesta, *Cydia* 155-159, 161, 192
molesta, *Grapholita* 155, 161
molesta, *Grapholitha* 155
molesta, *Salvinia* 332
molitrix, *Hypophthalmicthys* 322, 323
molliplum, *Diadegma* 123, 124
Monomorium antarcticum complex 162
montrouzieri, *Cryptolaemus* 145, 228-229, 230, 231, 33, 263, 264, 265
montserratensis, *Icerya* 207
Moranila californica 237, 238, 239
Mormoniella vitripennis 382
morning glory vine 67
Morphodexia barrosi 13
Morphodexia clausa 13
Morphodexia nigra 13
mothfly 251
mountain ash 217
Muehlenbeckia spp. 213
multicorne, *Austrosimulium* 376
multipunctata, *Austroaeschna* 376
munda, *Cycloneda* 58, 60
murinana, *Choristoneura* 81
Musca domestica 382, 387, 388, 392
Musca vetustissima 381, 384
muscid flies – see Muscidae

Muscidae 373, 383, 387-394
Muscidifurax raptor 388, 389
Muscidifurax uniraptor 388, 390, 391, 392
Muscidifurax zaraptor 388, 390, 391, 392
Muscidifurax spp. 389, 390, 391, 392
Muscina stabulans 387
Muscina spp. 388
musculus, *Anthocoris* 165, 218, 219, 246
musk thistle 339
mussel scale 181
mutans, *Graphania* 115, 116
myersi, *Nilaparvata* 184
myiasis 381
Mymaridae 185, 186
Myoporum laeta 225
Myriophyllum aquaticum 332
Myrtaceae 14
Mythimna separata 44, 52, 53, 69, 70, 107-109, 115, 116
Muscidfurax spp. 389
Mythimna separata 53
mytilaspidis, *Aphytis* 179, 180
myxomatosis 375
Myzocallis annulatus 307
Myzus persicae 55, 56

nabid – see Nabidae
Nabidae 56, 112
Nabis capsiformis 3, 4, 33, 57, 74
Nabis kinbergii 88
Nabis maoricus 57
Nabis punctipennis 24
napus, *Brassica* 55
napus var. *oleifera*, *Brassica* 47
nasalis, *Cermatulus* 51, 88, 115, 147, 189, 269, 281
Nasonia brevicornis 382
Nasonia vitripennis 382, 383, 395
nassaui, *Enoggera* 282, 285, 286
nasturtium 129
nasturtium-aquaticum, *Rorippa* 332
nebulosus, *Diastrophus* 358
nectarines 155, 161, 201, 217, 395
nematodes 14, 24, 31, 41, 121, 145, 189, 204, 214, 215, 305, 396
nemorum, *Anthocoris* 165, 218, 246
neoaphidis, *Erynia* 4
Neoaplectana sp. 74
Neochrysocharis trifolii 79-80
Neochrysocharis sp. 79
Neoleucopis tapiae 296
Neomolgus capillatus 30, 31
Neophyllobius sp. 179
Neopolycystus insectifurax 282, 285
Neoseiulus cucumeris 218
Neoseiulus fallacis 219, 246, 247-248
Neotoxoptera violae 62
Neozeleboria cryptoides 12
Neozeleboria volatilis 12
nerii, *Aspidiotus* 178, 180, 277
nervosa, *Agonopteryx* 368
Netelia producta 88, 107, 115
Neuroptera 60-61
New Zealand black fly 375-379
New Zealand flax 223
New Zealand flax mealybug 223, 224
Nezara viridula 44, 111-114
ngaio 225
niger, *Dendrocerus* 56
nightshade 119
nigra, *Morphodexia* 13
nigra, *Spalangia* 389
nigricornis, *Chrysopa* 60, 62
nigricornis, *Leucopis* 61, 63
nigroaena, *Spalangia* 388
nigromaculatus, *Exochomus* 232
Nilaparvata myersi 184
nitens, *Anaphes* 267
nitens, *Anaphoidea* 267
nitens, *Eucalyptus* 281
nitens, *Nymphula* 333
nitens, *Patasson* 267
Nitidulidae 155
noctilio, *Sirex* xi, xii, 255, 299-306
noctiluca, *Lampyris* 94
noctua, *Athene* 204
noctuid, noctuid moths – see Noctuidae
Noctuidae 19, 115-118, 361
nodding thistle 309, 339-342
nodiflorum, *Apium* 332
nordmannianae, *Adelges* 297
nordmannianae, *Dreyfusia* 297
Norfolk pines 229
nortoni, *Megarhyssa* 303
nortoni nortoni, *Megarhyssa* 300, 301, 304
Nosema carpocapsae 163
Nosema costelytrae 10
Nosema mesnili 129
Nosema takapauensis 10
Nosema sp. 11, 24, 116
Nothofagus spp. 225, 283, 286, 289, 290, 291
Notodytes aurea 40
Notodytes variabilis 40
Notodytes spp. 40
novae-zelandiae, *Acaenea* 313
novaezealandiae, *Melangyna* 57, 105
novozelandicus, *Xanthocryptus* 213, 215
NPV – see nuclear polyhedrosis virus
nuclear polyhedrosis virus 40, 116, 189
nuisance insects xi
nutans, *Carduus* 309, 339-342
Nyctemera annulata 361
nyctemeriana, *Pales* 107, 108
Nymphula nitens 333

oak 62, 217, 257, 259, 289, 307
oak aphid 307-308
oats 43, 105
obliqua, *Eucalyptus* 263
obliquana, *Ctenopeustis* 157, 187, 191
obliquus, *Listroderes* 97
obscura, *Leucopis* 61, 63, 296
obscuratus, *Thrips* 347
obscure mealybug 224
obscuricornis, *Sericophanes* 24
obscurus, *Conidiobolus* 4, 105
obscurus, *Pseudococcus* 224
occidentalis, *Metaseiulus* 219, 246, 248

occidentalis, *Typhlodromus* 219
Occisor versutus 39
ocellatella, *Scrobipalpa* 119
ochraceus, *Coccophagus* 237
oculata, *Chrysoperla* 60, 61
Ocytata pallipes 202, 203, 204
Odiaglyptus biformis 226
Odontothrips ulicilis 368
Odontria 18
Odontria autumnalis 13
Odontria smithi 12
Odontria striata 12
Odontria spp. 9, 13
Oechalia schellembergii 88, 115, 189, 269, 281
Oemona hirta 145, 213-216, 368
Oemona sp. 213
Oenopia sauzeti 59, 60, 64
OFM – see Oriental fruit moth
oil seed rape 56
oilseed crops 43
oleae, *Saissetia* 179, 237-240, 264
oleander 181
oleander scale 177, 178, 179, 181
oleracea var. *ramosa*, *Brassica* 46
olivacea, *Goniocteno* 348
olivacea, *Phytodecta* 348
olive 257
oncoperae, *Pleistophora* 51
oncoperae, *Vavraia* 10, 24, 51, 53, 54, 116
onion aphid 62
onions 43
Onopordum spp. 340
operculella, *Gnorimoschema* 119
operculella, *Phthorimaea* xi, xii, 43, 44, 116, 119-128
Ophelosia crawfordi 234
Ophelosia dactylopii 225, 226
Ophelosia spp. 226-227, 234
Opius phaseoli 48
Opius sp. 46, 47
orariensis, *Eriococcus* 310
orbitalis, *Pristomerus* 77, 80, 82
orchard crops 245
orchards 343
Orcus chalybeus 179, 180, 238, 258, 263, 264, 265
Orgilus lepidus 121, 122, 123, 124
Orgilus parcus 122, 124
orichalcea, *Thysanoplusia* 67, 71
Oriental fruit moth 155-159, 161, 192
orientalis, *Thuja* 59, 63
ornamental cherry 289
ornamental trees 153, 217, 289, 308
ornamentals 87, 177, 178, 237, 243
ornatus, *Misocyclops* 172
orthodoxus, *Thyreocephalus* 17
Orthosoma sp. 24
osculator, *Bracon* 77, 78, 82
ostraeformis, *Quadraspidiotus* 177, 178, 180
otakauensis, *Empis* 375
Ottelia ovalifolia 331, 332
ovalifolia, *Ottelia* 331, 332
ovata, *Eucalyptus* 283
oystershell scale 177, 178, 179, 181
PA – see pea aphid
Pachycrepoideus vindemiae 388, 389, 390, 391, 393
Pachycrepoideus spp. 389
Pachylister chinensis 389
Pachyneuron aphidis 106
Pachyneuron siphonophorae 56, 307
padi, *Rhopalosiphum* 55, 56, 59
Paecilomyces ?fumoso-roseus 74
Paecilomyces sp. 74
Pales efferata 51, 53
Pales feredayi 68
Pales funesta 188
Pales nyctemeriana 107, 108
Pales usitata 39
?Pales, *feredayi* 188
Palexorista laxa 88, 89
pallens, *Dalaca* 40
palliatus, *Hylurgops* 274
pallipes, *Ocytata* 202, 203, 204
pallipes, *Rhacodineura* 202
palmensis, *Chamaecytisus* 348, 369
palmeri, *Icerya* 207
palustre, *Cirsium* 341
palustris, *Quercus* 257
pampas grass 39
Panonychus ulmi 217-221, 245
panzeri, *Ctenichneumon* 52, 53
paradelpha, *Tachynomyia* 12
paradoxicus, *Metoecus* 396, 398
Paraleptomastix abnormis 232
Paraleptomastix sp. 232
Paraleurocerus bicoloripes 70
Parascaptomyza elmoi 46
Parasitoidea 217
Paratetranychus pilosus 217
parcus, *Orgilus* 122, 124
parda pastusa 120
paripennella, *Coleophora* 75
parkeri, *Stethantyx* 98
Parlatoria pittospori 177, 178, 180
Paropsinae 282
paropsine – see Paropsinae
Paropsis atomaria 282, 283
Paropsis charybdis xi, 255, 267, 281-287
Paropsis dilatata 281
Paropsis spp. 281
Paropsivora spp. 282
Parrotia spp. 289
Parsonsia spp. 213
parumbripennis, *Hydrobiosis* 375
parvistigma, *Austroaeschna* 376
paspalum 17
Paspalum dilatatum 17
Passiflora edulis 241
passionfruit 111
passionvine hopper 241-244
pasture xi, 9, 14, 17, 23, 39, 51, 107, 108, 115, 143, 223, 343
pasture grass 1, 226
pasture mealybug 224
Patagoniodes farinaria 361
Patasson nitens 267
pathogens 14, 41

pea aphid 3-7, 55
peaches 111, 155, 161, 201, 217, 395
pear leafcurling midge 171-175
pears 147, 155, 161, 171, 172, 217
peas 43, 87, 111
pectinicornis, *Pnigalio* 290, 291
Pediobius acantha 102, 103
Pediobius epigonus 102, 103
Pediobius sp. 189
pedunculata, *Quercus* 289
Pegohylemyia jacobaeae 363
Pegohylemyia seneciella 363
pennipes, *Trichopoda* 112-113, 114
Pennisetia marginata 358
Pennisetum clandestinum 17
pequodorum, *Praon* 4
perdistinctus, *Ecphoropsis* 89
peregrina, *Hungariella* 225
peregrina, *Tetracnemoidea* 225, 233, 234
perforatum, *Hypericum* 309, 310, 353-356
pergandiella, *Encarsia* 251
prob. *pergandiella*, *Encarsia* 251
Pericoptus 18
Pericoptus truncatus 13, 18, 20
Perilampus sp. 77, 82, 282, 283
Perilitus coccinellae 27
Periscepsia carbonaria 52, 53
perniciosi, *Encarsia* 179, 180, 181
perniciosus, *Quadraspidiotus* 177, 178, 180
perplexus, *Pilophorus* 173, 174
Perrisia plicatrix 358
Perrisia pyri 171
Persectania aversa 115
persicae, *Myzus* 55, 56
persimilis, *Phytoseiulus* 145, 219, 220, 246-47, 248, 249
persimmons 224
persuasoria himalayensis, *Rhyssa* 300, 301, 303, 305
persuasoria persuasoria, *Rhyssa* 299, 300, 301, 304, 305
peruviana, *Physalis* 119
Pezicula malicorticis 197
Phaenocarpa antipoda 381, 384, 385
Phalangiidae 57, 246
phalaris 105
phalloides, *Zoophthora* 4, 34
Phanerotoma fasciata 164, 166
Phanerotoma tibialis 164, 166
phaseoli, *Opius* 48
Phaseolus vulgaris 369
phaulacosoma, *Eutorna* 357
Phenacaspis eugeniae 177
Phenacoccus graminicola 223, 224, 225
Phenacoccus graminosus 224
philippiae, *Euxanthellus* 153, 237
philomelos, *Turdus* 93
Philonthus spp. 24
philoxeroides, *Alternanthera* 310, 325-330, 332
Phormium tenax 223
Phragmidium violaceum 358, 359
Phryxe vulgaris 129
Phthorimaea absoluta 119
Phthorimaea operculella xi, xii, 43, 44, 116, 119-128
phthorimaeae, *Chelonus* 121
phthorimaeae, *Microchelonus* 121
phya, *Brachymeria* 190, 191, 192
Phygadeuon vexator 204
Phylacteophaga froggatti 255
Phyllognathus excavatus 18
Phyllonorycter blancardella 289, 291
Phyllonorycter messaniella 255, 289-293
Phyllonorycter ulicicolella 368
Phyllophaga sp. 11
Phymatothynnus sp. 12
Physalis peruviana 119
Phytodecta olivacea 348
Phytoliriomyza spp. 45
Phytomyza atricornis 446
Phytomyza spp. 45
Phytoseiidae 218, 243, 246
Phytoseiulus macropilis 247
Phytoseiulus persimilis 145, 219, 220, 246-247, 248, 49
Picea spp. 271
picipes, *Aphidius* 4
Pieris brassicae 130, 132
Pieris rapae xii, 44, 129-134
pilipes, *Trichopoda* 113
Pilophorus perplexus 173
pilosus, *Paratetranychus* 217
pine twig chermes 295-297
pine woolly aphid 295-297
pines 271, 274, 299, 357
Pineus boerneri 295
Pineus laevis 255, 295-297
Pineus pini 295
Pineus strobi 295
pini var. *laevis*, *Kermaphis* 295
pini, *Pineus* 295
pinnata, *Azolla* 332
Pinus 305
Pinus radiata xi, 59, 63, 177, 178, 179, 295, 299, 302
Pinus spp. 271, 299
pipfruit 158, 161, 177, 178
Pipunculidae 184, 185
piricola, *Inostemma* 171, 172
piripiri 309, 313-315
pisivorus, *Aphidius* 4
Pisum sativum 48
pisum, *Acyrthosiphon* 1, 2, 3-7, 33, 84
pit scales 257-262
pittospori, *Parlatoria* 177, 178, 180
Pittosporum spp. 207
plaesiosema, *Scrobipalpa* 119
plaesiosema, *Symmectrischema* 119
plaesiosema, *Gnorimoschema* 119
plagiator, *Ephedrus* 5, 6
Plagiomyia longicornis 51, 53
Plagiomyia sp. 39
planchoniana, *Entomophthora* 4, 34, 105
planiceps, *Trite* 156
Planococcus citri 223, 231
Planococcus mali 223, 226, 234

Planotortrix excessana 157, 187
plant lice 55
Plantago spp. 351
platensis group *Temelucha* sp. 123, 124
Platygaster demades 172, 173, 174
Platygaster hiemalis 101, 102
Platygaster zosine 103
Platygaster sp. 172
Platyomus forestieri 237
Platyptilia falcatalis 191
Playtgaster hiemalis 103
Pleistophora oncoperae 51
Pleistophora sp. 27
plexippus, *Danaus* 115
plicatrix, *Dasineura* 358
plicatrix, *Perrisia* 358
Pliophorus perplexus 174
plorabunda, *Chrysoperla* 60, 61, 231
plumeless thistle 339
plums 147, 155, 181, 217, 395
Plusia chalcites 67
Plusiinae 67
Plutella antiphona 135, 139
Plutella maculipennis 135
Plutella sera 135
Plutella xylostella xii, 44, 81, 125, 135-142
Plutella spp. 135, 139, 140, 141
plutellae, *Apanteles* 136, 139
plutellae, *Cotesia* 139
Pnigalio pectinicornis 290, 291
poae, *Balanococcus* 223, 224, 226, 234
poae, *Pseudantonina* 224
podagrica, *Brachymeria* 382, 383
podocarp 225
Polistes humilis 147
pollen 201
Poltgonus spp. 325
polyhedral virus 129
polyhedrosis virus 135
pomaria, *Typhlocyba* 183, 184, 185
pomefruit 145, 146, 187, 217
pomonella, *Carpocapsa* 161
pomonella, *Cydia* 115, 155, 157, 161-169, 201, 217
pomonella, *Enarmonia* 161
pomonella, *Grapholita* 161
pomonella, *Grapholitha* 161
pomonella, *Laspeyresia* 161
Popillia japonica 10
popilliae, *Bacillus* 10
poplar 177
porina 1, 24, 39-42
poroporo 67, 69, 119
postvittana, *Epiphyas* xii, 155, 156, 157, 166, 87-195, 201
potato moth 119
potato tuber moth xi, 119-128
potato tuberworm 119
potatoes 17, 39, 43, 93, 97, 111, 119, 120, 125, 201
Potosia cuprea 18
poultry houses 391
praecellens, *Megarhyssa* 300, 304, 305
praetiosa, *Bryobia* 217
prairie grass 105
Praon barbatum 4, 5, 6
Praon pequodorum 4
pratense, *Trifolium* 73
?*pretiosa*, *Hungariella* 25
pretiosum, *Trichogramma* 90, 117, 162
pretiosus, *Tetracnemus* 225, 230
Pristomerus orbitalis 77, 80, 82
Pristonychus complanatus 156
Procecidochares utilis 317, 318
Procissio cana 9
Proctotrupidae 101
producta, *Netelia* 88, 107, 115
profundeicinis, *Acaena* 313
proletella, *Aleyrodes* 251
promissorius, *Ichneumon* 87, 107, 115
promissorius, *Pterocormus* 87, 115
Prosactogaster demades 172
protozoa 24
Prunus spp. 217, 289
Psecacera chilensis 13
Pseudantonina poae 224
Pseudaulacaspis eugeniae 177, 178, 180
Pseudelaphroptera brevipilosa 11, 12, 13, 14
pseudococcid – see Pseudococcidae
Pseudococcidae 223-236, 226, 227
Pseudococcus adonidum 224
Pseudococcus affinis 223, 224, 226, 227, 228, 232, 233, 234
Pseudcoccus calceolariae 223, 224, 225, 227, 230, 231, 232, 233, 234
Pseudococcus citrophilus 224
Pseudococcus comstocki 223, 224
Pseudococcus fragilis 224
Pseudococcus gahani 224, 230
Pseudococcus longispinus 223, 224, 225, 227, 228, 231, 232, 233, 234
Pseudococcus maritimus 223, 224, 233, 234
Pseudococcus obscurus 224
Pseudococcus sp. 225, 226, 233
Pseudoleucopis benefica 264
Pseudorhyssa maculicoxis 304
Pseudotsuga menziesii 271, 277
Psilopus mobilus 171
psociformis, *Conwentzia* 61, 63
psychid – see Psychidae
Psychidae 191
Psychoda spatula 251
Psychodidae 387
Psyllidae 286
psyllids – see Psyllidae
Pterocormus promissorius 87, 115
pteromalid – see Pteromalidae
Pteromalidae 46, 189, 281
Pteromalus puparum 129, 130-131, 132
Pteromalus semotus 77, 82
Pterostichus unistriatus 13, 40
ptyoptera, *Anisoplaca* 368
pubicornis, *Chrysocharis* 45, 47
pulchella, *Eucalyptus* 267
pulchellata, *Eupithecia* 351
Pullus sp. 230

pulses 43, 87
pumilio, *Diomus* 296
pumilio, *Scymnus* 296
pumpkins 67, 70, 87, 111
punctata, *Spirodella* 332
puncticornis, *Leucopis* 61, 63
punctipennis, *Nabis* 24
puniceus, *Clianthus* 45
puparum, *Pteromalus* 129, 130-131, 132
purchasi, *Icerya* viii, xii, 207-211, 263, 368
purpurea, *Digitalis* 309, 351-352
pustular scale 257
pycnocephalus, *Carduus* 339, 340, 341
Pyemotes zwoelferi 74, 76, 77, 78, 80, 82-83
Pyemotes sp. 74, 242
pyrastri, *Scaeva* 61, 63
pyreneata, *Eupithecia* 351
pyri, *Dasineura* 171-175
pyri, *Perrisia* 171
pyri, *Typhlodromus* 218, 220, 246
pyrifolia, *Pyrus* 217
pyrivora, *Contarinia* 171, 172
Pyronota 18
Pyrus communis 217
Pyrus pyrifolia 217

Quadraspidiotus ostraeformis 177, 178, 180
Quadraspidiotus perniciosus 177, 178, 180
quadridentata, *Ascogaster* 158, 164, 167
quadrigemina, *Chrysolina* 354, 355, 356
quadrilateralis, *Gonaxis* 93, 94
quadrimaculata, *Calliphora* 381, 382, 383
Quaylea dubius 239
quercicola, *Asterodiaspis* 257, 258
Quercus cerris 258, 291
Quercus ilex 290
Quercus palustris 257
Quercus pedunculata 289
Quercus robur 257, 258, 289-293
Quercus suber 290
Quercus spp. 257, 289, 307
quince 155
quinquemaculata, *Manduca* 131

radiata pine xi, 299, 305
radiata, *Eucalyptus* 283
radiata, *Pinus* xi, 59, 63, 177, 178, 179, 295, 299, 302
radicans, *Zoophthora* 129, 136, 139
radish 129
ragwort 45, 309, 358, 361-366
ragwort flea beetle 364
ragwort seedfly 363-364
ramburi, *Chrysopa* 60, 230, 234
raoi, *Diadegma* 124
rapae, *Artogeia* 129
rapae, *Diaeretiella* 56
rapae, *Pieris* xii, 44, 129-134
rapax, *Hemiberlesia* 177, 178, 180
rape 43, 47, 55, 129, 135
Raphidia sp. 164-165
raptor, *Muscidifurax* 388, 389
raspberries 9, 183, 217, 314, 358, 359
raspberry bud moth 357
raspberry cane wilt 357
rats 93
red clover 3, 75, 124
red mite 217, 245
red scale 180
red spider mite 245
red-berry disease 357
regis, *Tongyus* 226
regnans, *Eucalyptus* 263
remus, *Telenomus* 143, 144
repanda, *Coccinella* 60, 61
repens, *Trifolium* 33, 73, 74
Resedaceae 129
reticulatum, *Deroceras* 156
Retropinna retropinna 335
retropinna, *Retropinna* 335
Rhacodineura antiqua 202
Rhacodineura pallipes 202
Rhagigaster comparatus 12
Rhagigaster unicolor 12
Raphidia sp., 164
Rhigognostis sera 135
Rhinocyllus conicus 309, 340, 341, 343
Rhinotorus congruens 148, 149, 150
Rhizarcha sp. 46
Rhizoecus falcifer 223
Rhizophagus bipustulatus 272
Rhizophagus dispar 272
Rhizophagus ferrugineus 272
Rhizophagus spp. 274
Rhopalicus tutela 272-273
rhopaloceros, *Xanthopimpla* 101, 189, 190, 191, 192, 193
rhopalosiphi, *Aphidius* 105, 106
Rhopalosiphum padi 55, 56, 59
Rhopus anceps 226
Rhopus sp. A 226
Rhyssa alaskensis 304
Rhyssa amoena 300, 304, 305
Rhyssa crevieri 300, 304, 305
Rhyssa lineolata 299
Rhyssa persuasoria himalayensis 300, 301, 303, 305
Rhyssa persuasoria persuasoria 299, 300, 301, 304, 305
Rhyssa spp. 300, 304
Rhyzobius forestieri 237, 238, 264
Rhyzobius ventralis 153, 154, 237, 238, 255, 263, 264, 265
Ribautiana tenerrima 184
Ribes spp. 217
ribripes, *Brachymeria* 192
rice 143
rickettsia 10, 17
riparia, *Ageratina* 317
riverbed 347
RNA virus 10, 17
robur, *Quercus* 257, 258, 289-293
rodents 93, 94
Rodolia cardinalis xii, 145, 207, 208-209, 210
Rodolia iceryae 209
Rodolia sp. 208, 209
Rogas sp. 87, 107, 156

root crops 93
Rorippa microphylla 332
Rorippa nasturtium-aquaticum 332
Rosa indica 358
Rosa rubiginosa 310
Rosa sp. 358
Rosaceae 245
rosae, Aulacaspis 177, 178, 180
rose 177, 314
rose bushes 178
rose scale 177, 178
rose-grain aphid 55, 105-106
roseum, Trichothecium 242, 258
rubecula, Apanteles 129, 130, 132
rubella, Tachynomyia 12
rubi, Coraebus 358
rubi, Diastrophus 358
rubi, Lasioptera 358
rubiginosa, Rosa 310
rubripes, Brachymeria 191
rubromaculatus, Macrocentrus 51, 52, 107, 115
Rubus australis 314
Rubus fruticosus 309
Rubus fruticosus agg. 357-360
Rubus spp. 184, 357-360
rudd 333
ruficollis, Agrilus 358
ruficrus, Apanteles 44, 52, 53, 54, 68, 69, 70, 71, 87, 107, 108
?*ruficrus, Apanteles* sp. 188
ruficrus, Cotesia 52, 68, 107
rufifacies, Chrysomyia 381, 382, 384
rufipalpis, Agathis 75-76, 77, 78, 79, 81, 82, 84
rufiscutellaris, Glypta 158
rufithorax, Thynnoides 12, 13, 14
rufonotatus, Eridolius 148
rufopicta, Eirone 12
rush 325
rye 101, 105
ryegrass 25, 105

SAA – see spotted alfalfa aphid
Saissetia coffeae 239
Saissetia oleae 179, 237-240, 264
Salix sp. 263
Salmo gaidnerii 335
Salvinia molesta 332
San José scale 177, 178, 179, 180, 181
sandflies 373, 375
sanguinea, Cycloneda 58
Sarcophaga milleri 384
Sarcophagidae 383, 387
sarcophagidea, Dasyuromyia 13
Saropogon antipodus 9
sativa, Medicago 1, 3, 33
sativum, Pisum 48
sauzeti, Oenopia 59, 60, 64
saxonica, Dolichovespula 395, 397, 398
Scaeva pyrastri 61, 63
scales 10, 201
Scambus brevicornis 77, 81
Scaptomyza elmoi 46, 48
Scaptomyza fuscitarsus 48
Scaptomyza graminum 46
Scaptomyza spp. 46, 48
Scarabaeidae 14, 18
Scardinius erythrophthalmus 333
Scarites spp. 18, 19, 20
scelionid – see Scelionidae
Scelionidae 242
schauinslandi, Guiglia 299
Schefflera spp. 213
schellembergii, Oechalia 88, 115, 189, 269, 281
Schizoneura lanigera 197
Schlettererius cinctipes 300, 304, 305
Sclerotinia fructicola 155
Scolia sp. 11
scoliid – see Scoliidae
Scoliidae 18
Scoliinae 11
Scolypopa australis 241-244
scolypopae, Centrodora 242, 243
scoparium, Leptospermum 310
scoparius, Cytisus 310, 347-349
Scrobipalpa heliopa 119
Scrobipalpa ocellatella 119
Scrobipalpa plaesiosema 119
Scrobipalpa spp. 119
Scrobipalpopsis solanivora 119
Scrobipalpula absoluta 121
scrub 225
scutellare, Apion 368
scutellaris, Apanteles 122, 124
scutellaris, Coccophagus 153
scutellatus, Gonipterus 255, 267-269
Scutellista cyanea 239
Scymnodes forestieri 237
Scymnus binaevatus 232
Scymnus fagus 179
Scymnus loewi 228
Scymnus pumilio 296
Scymnus sordidus 232
Scymnus sp. 217, 232
Scythris gallicella 368
Scythris grandipennis 368
Sejanus albisignata 162, 184, 218, 246
selenophora, Dasypoda 115
sellowiana, Feijoa 155
semialbiclavus, Hemiptarsenus 45, 47
semiclausum, Diadegma 44, 125, 136, 137, 138, 139, 140
semotus, Pteromalus 77, 82
seneciella, Botanophila 363
seneciella, Pegohylemyia 363
Senecio jacobaea 45, 309, 361-366
senecionella, Melanagromyza 45, 361
senilis, Thynnoides 12
separata, Mythimna 44, 52, 69, 70, 107-109, 115, 116
septempunctata, Coccinella 59, 60, 64
sera, Plutella 135
sera, Rhigognostis 135
sericata, Lucilia 381, 382, 383, 384
Sericophanes obscuricornis 24
Sericothrips staphylinus 368
Serratia entomophila 10, 14
serratulae, Gueriniella 207
setipennis, Bigonicheta 202
setipennis, Triarthria 202, 203, 204
sexannulatus, Cryptus 164, 166

seychellarum, *Icerya* 207
shelter 177, 178
sicarius, *Apanteles* 188
signata, *Wiseana* 39
Signiphora flavella 179, 180
Signiphora merceti 179, 180
silver carp 322
silver eye 57, 156
silver Y moth 67
silver-beet 111, 143
silverbeet – see silver-beet
silvereye – see silver eye
Silybum marianum 310
Silybum spp. 340
Simulium 377
siphonophorae, *Pachyneuron* 56, 307
Sirex noctilio xi, xii, 255, 299-306
sirex wood wasp 299-306
siricidicola, *Deladenus* 255, 299
Sitobion miscanthi 55, 56
Sitona discoideus 1, 2, 25, 27-28
sitona weevil 27-28
slender-winged thistle 339
slugs 93
small white butterfly xii, 129-134
Sminthurus viridis 29-32
smirnovi, *Turanogonia* 52
smithi, *Aphidius* 4, 5-6, 7
smithi, *Odontria* 12
Smynthurus viridis 29
sociella, *Aphomia* 396
soft fruit crops 93
Solanaceae 119, 125
solanivora, *Scrobipalpopsis* 119
Solanum aviculare 67, 119, 213
Solanum mauritianum 213
Solanum spp. 119
Sonchus sp. 47
song thrush 93
sonorensis, *Campoletis* 90
sooty moulds 184, 185, 224, 237, 241, 251, 263, 307
Sophora tetraptera 63
Sophora spp. 213
Sorbus spp. 217
sordidus, *Scymnus* 232
sorghum 87
southern armyworm 115
soybeans 67, 69, 70, 111
Spalangia calcitrans 388
Spalangia cameroni 388, 389, 392
Spalangia endius 388, 389, 390, 391, 392
Spalangia nigra 389
Spalangia nigroaena 388
Spalangia spp. 388, 389
spartiella, *Anarsia* 368
spartifoliella, *Leucoptera* 347, 348
spatula, *Psychoda* 251
spermotrophus, *Megastigmus* 255, 277-279
spermotrophus, *Mesopolobus* 277, 278
sphaerosperma, *Entomophthora* 129
Sphecophaga 396
Sphecophaga burra 396
Sphecophaga vesparum 396
Sphecophaga vesparum burra 396, 399
Sphecophaga vesparum vesparum 396, 397, 398, 399
Sphegigaster sp. 388, 389
sphondylium, *Heracleum* 202
spiders 33, 57, 88, 105, 112, 156, 163, 171, 184, 185, 193, 201, 241
spinach 45
spinipennis, *Bigonicheta* 202, 203
spinipennis, *Digonichaeta* 202
spiralis, *Vallisneria* 332
Spirodella punctata 332
spissicornis, *Coleophora* 73-85
splendens, *Achrysocharoides* 290, 291, 292
splendens, *Enaysma* 290
Spodoptera litura 143-144
Spodoptera spp. 143
spotted alfalfa aphid 4, 6, 33-37, 55
spruce 272, 299
squash 43
St John's wort 309, 310, 353-356
St John's wort midge 354
stable fly 387
stabulans, *Muscina* 387
stagnalis, *Callitriche* 332
staphylinus, *Sericothrips* 368
starlings 10, 27, 74
Stathmopoda horticola 191
Stathmopoda melanochra 264
Stathmopoda spp. 157
Steinernema bibionis 30, 39, 41, 214, 215
Steinernema feltiae 214
Steinernema glaseri 11, 14, 41
stellenboschense, *Diadegma* 123
sternalis, *Dasyuromyia* 13
Stethantyx, *argentinensis* 98
Stethantyx parkeri 98
Stethantyx spp. 97, 98, 99
Stethaspis 18
Stethorus bifidus 218, 246
Stethorus spp. 156, 249
stigma, *Hemerobius* 296
Stigmaeidae 218, 246
stokesii, *Gambrus* 157, 166, 192
stokesii, *Glabridorsum* 156, 157, 158, 166, 190, 191, 192, 193
stokesii, *Ischnus* 157, 166, 192
Stomoxys calcitrans 387, 388, 392
stonefruit 55, 146, 155, 201, 202, 217
stramineipes, *Alysia* 381, 384
strawberry 9, 17, 190, 245, 246, 314, 358, 359
striata, *Odontria* 12
strichnocera, *Dictyonota* 368, 369
strobi, *Pineus* 295
strobilorum, *Agnomus* 277
Sturnus vulgaris 10, 74, 162
stygia, *Calliphora* 381, 382, 383, 384
subandinus, *Apanteles* 122, 123, 124, 125
?*subandinus*, *Apanteles* 122
suber, *Quercus* 290
subflavescens, *Aphelinus* 307-308
subnigrescens, *Mermis* 204
Subprionomitus ferus 226
subtilicornis, *Diadromus* 139
succedana, *Cydia* 368
sugar beet 119

summerfruit, 55, 155, 158, 177, 178, 201
surandrai, *Diadegma* 124
swedes 43, 129, 135
sweet briar 310
sweet corn – see sweetcorn
sweet potato 17, 143
sweetcorn 43, 51, 87, 88, 108, 201
sydneyensis, *Anarhopus* 226
sydneyensis, *Tetracnemoidea* 226, 233, 234
sylvestris, *Malus* 289
Symmectrischema plaesiosema 119
Sympherobius barberi 61, 63, 232
Sympherobius californicus 61, 63, 232, 234
Sympherobius spp. 227, 232
Symphyomyrtus 281
Symphypleona 30
Symphytum uplandicum x, 69
Sympiesis spp. 188
Synanthedon tipuliformis 201
synanthropic flies 387
syngenesiae, *Chromatomyia* 45, 361
Synomelix sp. 148, 149, 150, 151
Syrphidae 56, 57, 136, 189, 295
syrphids – see Syrphidae

Tachinaephagus zealandicus 381, 383, 384, 388, 389
tachinid, tachinids – see Tachinidae
Tachinidae 11, 12, 13, 14, 18, 52, 88, 89, 188, 190, 191, 268, 281, 283
Tachininae 11
Tachiniphaegus zealandicus 385
Tachynomyia paradelpha 12
Tachynomyia rubella 12
takapauensis, *Nosema* 10
tamarillo 111, 119, 251
Tanaomastix abnormis 232
tapiae, *Leucopis* 295-296, 297
tapiae, *Neoleucopis* 296
taro 143
tarsalis, *Dasyuromyia* 13
tasmaniae, *Micromus* 3, 4, 6, 33, 57, 64, 88, 105, 197, 227
tasmanicus, *Apanteles* 188, 189, 190
tawaki, *Leucocytozoon* 375
telarius, *Tetranychus* 245
Telenomus remus 143, 144
tellarius, *Tetranychus* 245
Telopia sp. 178
Temelucha sp. *platensis* group 123, 124
Temelucha sp. 190
Temnorhynchus 18
templi, *Dasypolia* 202
tenax, *Phormium* 223
tenebrionis, *Adelina* 17, 20
tenellus, *Gelis* 156, 157
tenerrima, *Ribautiana* 184
tenuiflorus, *Carduus* 339, 340, 341
tersilochine – see Tersilochini
Tersilochini 98
Tetracnemoidea bicolor 226
Tetracnemoidea brevicornis 225, 230, 232, 233, 234
Tetracnemoidea brounii 225
Tetracnemoidea peregrina 225, 233, 234
Tetracnemoidea sydneyensis 226, 233, 234
Tetracnemoidea zelandica 226
Tetracnemus brounii 225
Tetracnemus pretiosus 225, 230
Tetracnemus n. sp. 230
Tetracnemus sp. 225, 230
Tetranychus lintearius 368, 369-370
Tetranychus telarius 245
Tetranychus tellarius 245
Tetranychus urticae 145, 218, 219, 245-250, 370
tetraptera, *Sophora* 63
Tetrastichus charoba 102
Tetrastichus evonymellae 347, 348
Tetrastichus sp. 46, 47, 48
teuta, *Brachymeria* 190, 191, 192
Thanasimus formicarius 272, 273
Thelohaniidae 375
therevids 10
Therioaphis trifolii 1
Therioaphis trifolii f. *maculata* 33-37
thistles 97
threadworms 202, 204
Thripidae 28, 246
thrips 258
Thrips obscuratus 347
Thuja orientalis 59, 63
thuringiensis, *Bacillus* 53, 90, 116, 132, 135
thuringiensis var. *israelensis*, *Bacillus* 376, 378
Thyatira batis 358
Thynninae 10, 11, 12, 14
Thynnoides gracilis 12
Thynnoides laeviceps 12
Thynnoides lugubris 12
Thynnoides rufithorax 12, 13, 14
Thynnoides senilis 12
Thyraeella collaris 138-139
Thyreocephalus chloropterus 10, 39
Thyreocephalus orthodoxus 17
Thysanoplusia orichalcea 67, 71
tibialis, *Phanerotoma* 164, 166
Tilapia spp. 333
tillyardi, *Froggattimyia* 282
tillyardomyia, *Austrosimulium* 375
tincticollis, *Trachymela* 282
tinctoria, *Genista* 369
Tiphia transvaalensis 18, 19
Tiphia sp. 11, 13
Tiphiidae 18
tipuliformis, *Synanthedon* 201
tobacco 67, 69, 87, 97, 119, 143
tobacco leaf miner 119
tobacco looper 67
tomato fruit moth 119
tomato fruitworm 87-91
tomato hornworm 131
tomato stem borer 119
tomatoes 43, 67, 69, 87, 88, 89, 97, 111, 112, 117, 119, 143, 251
Tongyus costalis 226
Tongyus regis 226
tonsus, *Gelis* 77, 81
Tortricidae 188, 347
tortricids – see Tortricidae
Torymoides sp. 356
Torymus chloromerus 172, 174

Trachymela tincticollis 282
transvaalensis, *Tiphia* 18, 19
transversoguttata, *Coccinella* 59, 60
trees 9, 218
trefoils 3
Trialeurodes vaporariorum 145, 251-254
Triarthria setipennis 202, 203, 204
Triaspis sp. 98
Trichogramma australicum 116
Trichogramma bactrae 68
Trichogramma chilonus 116, 117
Trichogramma dendrolimi 116, 117
Trichogramma euproctidis 116, 117
Trichogramma evanescens 116, 117
Trichogramma ivelae 90
Trichogramma maidis 116
Trichogramma ?minutum 162
Trichogramma pretiosum 90, 117, 162
Trichogramma spp. 68, 71, 88, 90, 116, 117, 118, 121, 140, 147, 156, 162, 163, 188
Trichogramma (*Trichogrammanza*) *funiculatum* 67, 68, 115, 188
Trichogramma (*Trichogrammanza*) spp. 156, 158
Trichogrammatidae 115, 118
Trichogrammatoidea bactrae 67, 115
Trichogrammatoidea bactrae fumata 188
Trichogrammatoidea sp. 87, 115
Trichomalopsis sp. 108, 137, 138, 139, 156, 188
Trichopoda pennipes 112-113, 114
Trichopoda pilipes 113
Trichopoda spp. 111
Trichopria sp. 388
Trichoprosopus latifrons 13
Trichosirocalus horridus 340, 341
Trichothecium roseum 242, 258
trifolii f. *maculata*, *Therioaphis* 33-37
trifolii, *Chrysonotomyia* 77, 78, 79-80, 83, 84
trifolii, *Coleophora* 74, 75, 76, 77, 78, 80
trifolii, *Liriomyza* 48
trifolii, *Neochrysocharis* 79-80
trifolii, *Therioaphis* 1
Trifolium arvense 73
Trifolium fragiferum 73
Trifolium hybridum 73
Trifolium pratense 73
Trifolium repens 33, 73, 74
Trifolium spp. 81
Trigonospila brevifacies 156-157, 190, 191, 192, 193
Trionymus diminutus 224
Trionymus spp. 227
Trioxys complanatus 34, 35, 36
Trioxys sp. 307
Trirammatus unistriatus 13, 40
Trissolcus basalis 111, 112, 113, 114
Trissolcus spp. 111
Trite minax 156
Trite planiceps 156
trochanterus, *Eriborus* 122, 124
Trombidoidea 217
Tropaeolaceae 129
Tropaeolum majus 48
tropical armyworm 143-144
trout 335
trout fisheries 321
truncatellum, *Copidosoma* 69
truncatellum, *Litomastix* 69
truncatus, *Pericoptus* 13, 18, 20
tryphonoides, *Ariphron* 12
Tuberculatus annulatus 255, 307-308
Turanogonia chinensis 52
Turanogonia smirnovi 52
turcator, *Diadegma* 122, 124
Turdus merula 93
Turdus philomelos 93
turf grass 23
turkey oak 258
turnips 43, 47, 97, 129
turrita, *Vibrissina* 149
tussock country 343, 353
tussock grass 39, 225
tutela, *Rhopalicus* 272-273
tutu 241
two-spotted mite 145, 245-250
Typhlocyba froggatti 183-186
Typhlocyba pomaria 183, 184, 185
typhlocybae, *Aphelopus* 185
Typhlocybinae 184
Typhlodromus caudiglans 246
Typhlodromus occidentalis 219
Typhlodromus pyri 218, 220, 246
Tyria jacobaeae 362-363

Ucona acaenae 313, 314
Ulex europaeus 309, 367-371
ulicetella, *Agonopterix* 368, 369
ulicicolella, *Phyllonorycter* 368
ulicilis, *Odontothrips* 368
ulicis, *Apion* 369, 370
ulicis, *Asphondylia* 368
ulmi, *Lepidosaphes* 177, 178, 180
ulmi, *Metatetranychus* 217
ulmi, *Panonychus* 217-221, 245
Ulmus americana 197
Umbelliferae 11, 14
umbraculata, *Wiseana* 39
undecimpunctata, *Coccinella* xii, 3, 27, 33, 43, 7-58, 60, 63, 64, 105, 145, 208
ungulatum, *Austrosimulium* 375, 377
unicolor, *Adelencyrtoides* 226
unicolor, *Agathis* 121, 122, 123
unicolor, *Rhagigaster* 12
unicolorata, *Agathis* 123
unicornis unicornis, *Austroaeschna* 376
uniraptor, *Muscidifurax* 388, 390, 391, 392
uniseta, *Dexia* 19
uniseta, *Voriella* 189, 190, 191
unistriatus, *Pterostichus* 13, 40
unistriatus, *Trirammatus* 13, 40
x *uplandicum*, *Symphytum* 69
uredinis, *Kuhneola* 357
Urophora cardui 343-344
urticae, *Aphidius* 4
urticae, *Tetranychus* 145, 218, 219, 245-250, 370
uruguayensis, *Copidosoma* 124
usitata, *Pales* 39
ustistriga, *Graphania* 115, 116
utilis, *Procecidochares* 317, 318

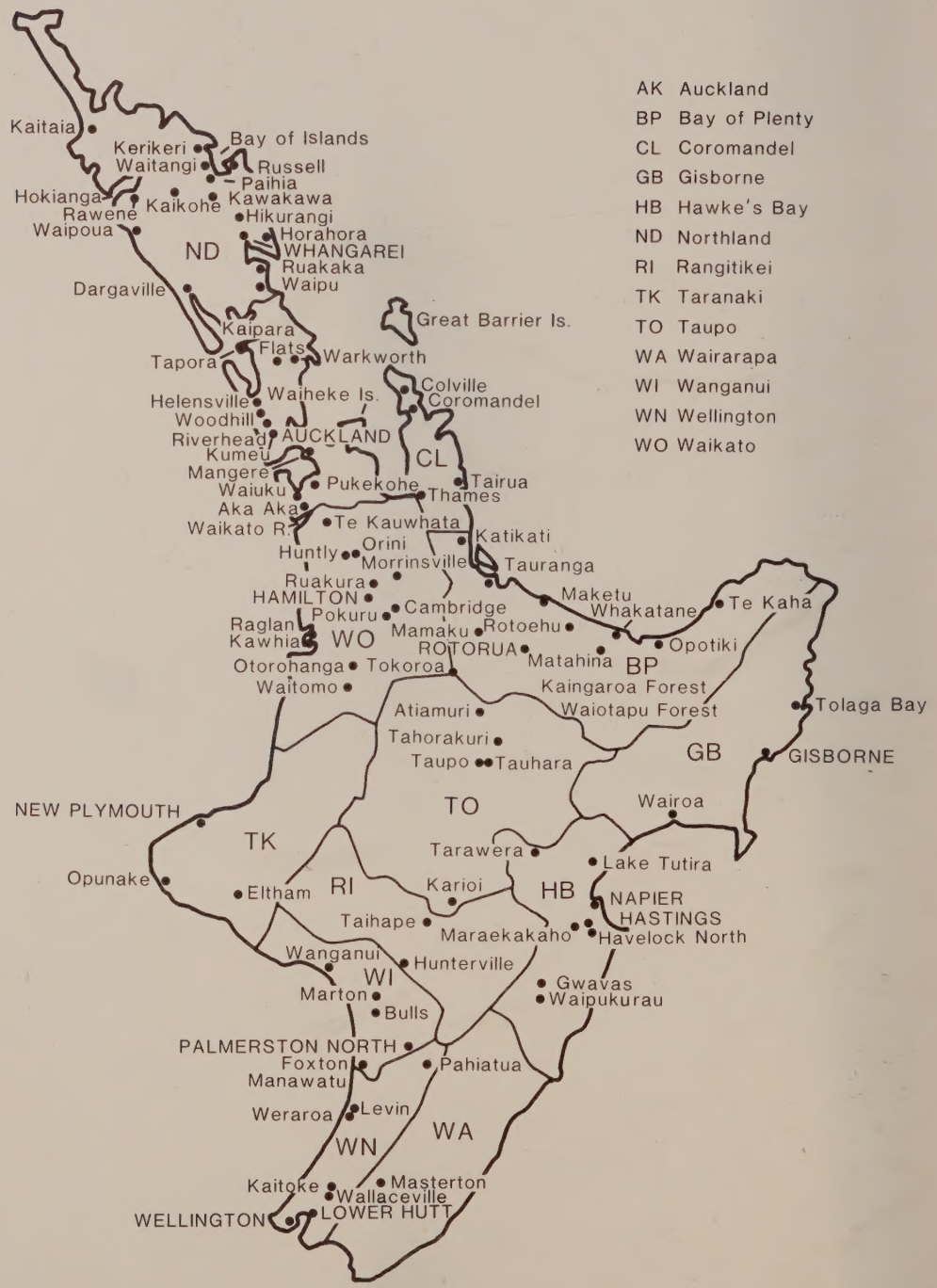
Vallisneria spiralis 332
vaporariorum, *Trialeurodes* 145, 251-254

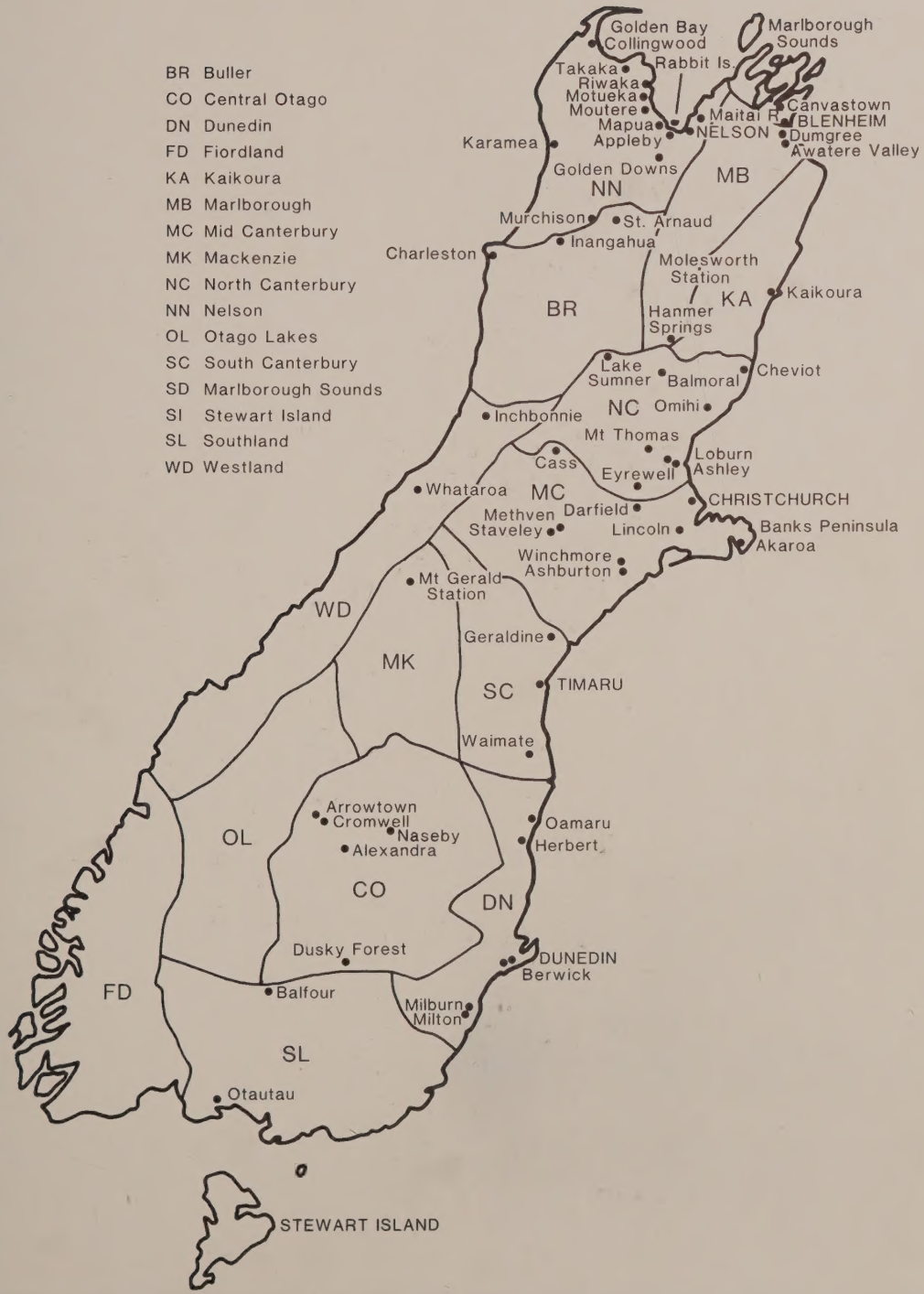
varia, *Hybopygia* 384, 385, 388
variabilis, *Dalaca* 40
variabilis, *Notodytes* 40
variegated thistle 310
variegator, *Bracon* 77, 78, 79, 83, 84
varinervus, *Antholcus* 314
variolosa, *Asterodiaspis* 257, 258
variolosus, *Aphycus* 258
varius, *Itamus* 9
Vavraia oncoperae 10, 24, 51, 53, 54, 116
vegetable crops 140, 143
vegetable weevil 97-99
vegetables xi, 201
veneta, *Elsinoe* 357
ventralis, *Rhyzobius* 153, 154, 237, 238, 255, 263, 264, 265
prob. *versicolor*, *Hirsutella* 242
versutus, *Occisor* 39
verticillata, *Hydrilla* 332
Verticillium lecanii 56, 251
veruculata, *Achaearanea* 156, 193
vesicularis, *Macroneura* 101, 102, 103
vesparum, *Dibrachys* 398
vesparum, *Sphecophaga* 396
vesparum burra, *Sphecophaga* 396, 399
vesparum vesparum, *Sphecophaga* 396, 397, 398, 399
vespid wasps – see Vespidae
Vespidae 373
Vespula atropilosa 396
Vespula germanica 113, 241, 281, 375, 382, 395-399
Vespula vulgaris 382, 395-399
Vespula spp. 189, 396
vetustissima, *Musca* 381, 384
vexator, *Phygadeuon* 204
Vibrissina turrita 149
vicina, *Calliphora* 382, 383, 384
victrix, *Alloxysta* 56, 106
villosus, *Bruchidius* 348
viminalis, *Eucalyptus* 263, 267, 281
vindemiae, *Pachycrepoideus* 388, 389, 390, 391, 393
vineyards 227, 234
violaceum, *Phragmidium* 358, 359
violae, *Neotoxoptera* 62
virescens, *Altica* 313, 314
virescens, *Heliothis* 88
viridis, *Sminthurus* 29-32
viridis, *Smynthurus* 29
viridula, *Nezara* 44, 111-114
virus transmission 55, 56
viruses 41
  arbovirus 375
  cytoplasmic polyhedrosis 116
  entomopox 40
  Flock House 10
  granulosis 40, 120, 121, 129, 131, 135, 167
  Helicoverpa polyhedrosis 116
  iridescent 10
  nuclear polyhedrosis 40, 116, 189
  polyhedral 129
  polyhedrosis 135
  RNA 10, 17
vitripennis, *Mormoniella* 382
vitripennis, *Nasonia* 382, 383, 395
Vogtia malloi 325, 326, 327, 329
volatilis, *Neozeleboria* 12
Voriella uniseta 189, 190, 191
vulgare, *Foeniculum* 11
vulgaris, *Phaseolus* 369
vulgaris, *Phryxe* 129
vulgaris, *Sturnus* 10, 74, 162
vulgaris, *Vespula* 382, 395-399

walls 143
walnuts 161, 217
waratah 177, 178
waratah scale 177, 178
wasteland 347
water hyacinth 325
waterweeds 309, 331-336
wattle 19
weeds xi, 108, 125, 218
weedy areas 115
weevils 18
West Coast black fly 375
Whataroa M78 375
wheat 23, 43, 51, 55, 101, 103, 105
white clover 3, 33, 35, 73, 74, 75, 83
white fly 145
whitetipped clover casebearer 73-85
willow 40, 177
willow weed 325
wilt disease 129
winged thistle 339
Wiseana cervinata 39
Wiseana despecta 39
Wiseana signata 39
Wiseana umbraculata 39
Wiseana spp. 1, 24, 39-42
woolly apple aphid xii, 55, 57, 145, 197-199

Xanthocryptus novozelandicus 213, 215
Xanthopimpla rhopaloceros 101, 189, 190, 191, 192, 193
Xenocalliphora hortona 381
Xyaloplothrips sp. nr. *fuliginosus* 218
Xylaplothrips sp. 246
xylostella, *Plutella* xii, 44, 81, 125, 135-142

Zaomma lambinus 180
zaraptor, *Muscidifurax* 388, 390, 391, 392
Zatropis sp. 24
zealandica, *Anacharis* 57, 197
zealandica, *Costelytra* x, xii, 1, 9-16, 18, 20, 24, 40
zealandicus, *Tachinaephagus* 381, 383, 384, 385, 388, 389
zelandica, *Tetracnemoidea* 226
Zelaphycus aspidioti 180
Zelarchertus sp. 188
zetterstedtii, *Epitetracnemus* 180
Zeuxidiplosis giardi 354, 356
zinnias 97, 201
Zoophthora aphidis 105
Zoophthora phalloides 4, 34
Zoophthora radicans 129, 136, 139
zosimus, *Aprostocetus* 102, 103
zosine, *Platygaster* 103
Zosterops lateralis 57, 156, 162, 163
zwoelferi, *Pyemotes* 74, 76, 77, 78, 80, 82-83


AK Auckland
BP Bay of Plenty
CL Coromandel
GB Gisborne
HB Hawke's Bay
ND Northland
RI Rangitikei
TK Taranaki
TO Taupo
WA Wairarapa
WI Wanganui
WN Wellington
WO Waikato
Kaitaia
Kerikeri
Bay of Islands
Waitangi
Russell
Paihia
Hokianga
Kaikohe
Kawakawa
Rawene
Hikurangi
Waipoua
Horahora
ND
WHANGAREI
Ruakaka
Waipu
Dargaville
Great Barrier Is.
Kaipara
Flats
Tapora
Warkworth
Colville
Coromandel
Helensville
Waiheke Is.
Woodhill
Riverhead
AUCKLAND
Kumeu
CL
Mangere
Waiuku
Pukekohe
Tairua
Thames
Aka Aka
Waikato R.
Te Kauwhata
Katikati
Huntly
Orini
Morrinsville
Tauranga
Ruakura
HAMILTON
Maketu
Whakatane
Te Kaha
Pokuru
Cambridge
Raglan
Kawhia
WO
Mamaku
Rotoehu
Opotiki
ROTORUA
Matahina
BP
Otorohanga
Tokoroa
Waitomo
Kaingaroa Forest
Waiotapu Forest
Tolaga Bay
Atiamuri
Tahorakuri
GB
GISBORNE
Taupo
Tauhara
TO
Wairoa
NEW PLYMOUTH
TK
Tarawera
Lake Tutira
Opunake
Eltham
RI
Karioi
HB
NAPIER
HASTINGS
Taihape
Maraekakaho
Havelock North
Wanganui
Hunterville
WI
Gwavas
Waipukurau
Marton
Bulls
PALMERSTON NORTH
Foxton
Pahiatua
Manawatu
Weraroa
Levin
WA
WN
Kaitoke
Masterton
Wallaceville
WELLINGTON
LOWER HUTT


BR Buller
CO Central Otago
DN Dunedin
FD Fiordland
KA Kaikoura
MB Marlborough
MC Mid Canterbury
MK Mackenzie
NC North Canterbury
NN Nelson
OL Otago Lakes
SC South Canterbury
SD Marlborough Sounds
SI Stewart Island
SL Southland
WD Westland
Golden Bay
Collingwood
Marlborough Sounds
Takaka
Rabbit Is.
Riwaka
Motueka
Moutere
Mapua
Maitai R.
Canvastown
BLENHEIM
NELSON
Dumgree
Awatere Valley
Karamea
Appleby
Golden Downs
NN
MB
Murchison
St. Arnaud
Inangahua
Charleston
Molesworth Station
KA
Kaikoura
BR
Hanmer Springs
Lake Sumner
Balmoral
Cheviot
NC
Omihi
Inchbonnie
Mt Thomas
Cass
Loburn
Ashley
Eyrewell
Whataroa
MC
CHRISTCHURCH
Methven
Darfield
Staveley
Lincoln
Banks Peninsula
Akaroa
Winchmore
Ashburton
Mt Gerald Station
WD
Geraldine
MK
SC
TIMARU
Waimate
Arrowtown
Cromwell
Naseby
Alexandra
Oamaru
Herbert
OL
CO
DN
Dusky Forest
DUNEDIN
Berwick
FD
Balfour
Milburn
Milton
SL
Otautau
STEWART ISLAND